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PROGRAM FOR PREVENTING AND ELIMINATING OIL POLLUTION OF THE BUFFALO RIVER

R. C. Ziegler

Cornell Aeronautical Laboratory, Incorporated

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This report summarizes work performed under a program for "Prevention and Elimination of Oil Pollution of the Buffalo River." This program included many analytical, design, experimental, and development subtasks. The design, fabrication, and field testing of a pneumatic barrier system was undertaken for restraining the flow of surface oil in the Buffalo River, and laboratory tests were performed to obtain performance data under extended flow conditions. An extensive sampling program to determine the distribution and characteristics of oil pollutants on the river was carried out and various oil sampling techniques were devised and evaluated. In-sewer instruments for detecting thin and thick surface oil films and oil in bulk water were designed, fabricated and tested in the Buffalo sewer system. A telemetering system relayed oil accumulation data to a central facility. Specifications for an oil and debris removal boat and its associate equipment were prepared. Methods were developed for evaluating oil skimmer performance. The oil trapping characteristics of inverted siphons were investigated. Various oil boom configurations were evaluated.

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FOREWORD

The multi-media character of pollution resulting from the extraction, processing, conversion, and utilization of energy and mineral resources and from industrial processing and manufacturing operations requires a research approach which recognizes the complex environmental impact of these operations.

The Industrial Environmental Research Laboratory-Cincinnati utilizes a multidisciplinary approach in the development and demonstration of technologies to effectively deal with the pollution associated with these operations. The Laboratory assesses the environmental impacts of industrial and energy-related activities and identifies, evaluates and demonstrates control alternatives.

This report is a product of the above efforts. It summarizes work performed on the design, fabrication and field testing of a pneumatic barrier for restraining the flow of surface oil. This project is an effort in the Environmental Protection Agency program to develop control technology for oil and hazardous spills.

David G. Stephan
Director
Industrial Environmental Research Laboratory-Cincinnati

ABSTRACT

This report summarizes work performed under a program for "Prevention and Elimination of Oil Pollution of the Buffalo River." This program included many analytical, design, experimental, and developmental subtasks. The design, fabrication, and field testing of a pneumatic barrier system was undertaken for restraining the flow of surface oil in the Buffalo River, and laboratory tests were performed to obtain performance data under extended flow conditions. An extensive sampling program to determine the distribution and characteristics of oil pollutants on the river was carried out and various oil sampling techniques were devised and evaluated. In-sewer instruments for detecting thin and thick surface oil films and oil in bulk water were designed, fabricated, and tested in the Buffalo sewer system. A telemetering system relayed oil accumulation data to a central facility. Specifications for an oil and debris removal boat and its associate equipment were prepared. Methods were developed for evaluating oil skimmer performance. The oil trapping characteristics of inverted siphons were investigated. Various oil boom configurations were evaluated.

This report was submitted in fulfillment of Program Number 11020 DJG, Grant Number WPRD 263-01-68 by Calspan Corporation (formerly Cornell Aeronautical Laboratory, Inc.) under the partial sponsorship of the U.S. Environmental Protection Agency.

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SECTION I
CONCLUSIONS

Specific conclusions and findings based on work performed under Federal Grant WPRD 263-01-68 on a "Program for Preventing Oil Pollution of the Buffalo River" are presented below. Our general observation is that this program helped to focus the attention of local residents and industries on the gross pollution problem that has persisted in this river for decades and that this increased concern has resulted in positive action to eliminate the problem.

PNEUMATIC BARRIERS

1. Pneumatic barriers can be designed, built and installed in a river to restrain surface oils in low currents of less than 1 foot per second. ~~second~~.

2. The stream current at which a pneumatic barrier fails to restrain surface oils is dependent on oil viscosity and specific gravity. The currents at which serious breakthrough was found to occur for different oil types tested in the program are shown below.

Oil Type	Current At Which Serious Breakthrough Occurs
No. 2 Fuel	0.7 fps
No. 6 Fuel	1.3-1.5 fps
Bachaquero Crude	0.8 fps
South Louisiana Crude	1.0 fps

3. A single pneumatic barrier can be an economical device for restraining oil for unidirectional currents less than 1 foot per second.

4. Multiple pneumatic barriers located near the source of oil are suggested for containing oil in rivers in which there are frequent changes in current direction as is the case for the Buffalo River.

5. A system of two or more pneumatic barriers could provide an effective means for containing oil spills on the Buffalo River since most of the time the flow is less than 1 foot per second.

6. The air required to form a stagnation zone (a necessary but not sufficient condition to restrain oil) increases from 4 scfm/ft for 1 fps current to 100 scfm/ft for a 2.5 fps current.

DETECTION OF OIL IN SEWERS

1. A device based on the ultraviolet transmission characteristics of oil was developed which is capable of sensing oil dispersed in bulk water over the range of 5 to 10,000 parts per million, or surface films of oil ranging in thickness from a few microns to about 1 millimeter.

2. Radio frequency and heat conductivity sensors were developed which can detect massive oil accumulations from a few millimeters to several meters thick.

3. The three types of sensors mentioned in 1 and 2 above were tested in sewers and found to remain functional for periods of months, with some maintenance required for the more sensitive sensors at intervals of weeks.

4. The above sensors were compatible with narrow-based, low-duty-cycle telemetry which permits central readout of measurements from many sensors.

5. The estimated costs of the above sensors range from less than $100 per sensor for the conductivity units to a few hundred dollars for the UV transmission sensor.

SAMPLING AND IDENTIFICATION

1. Because of the very large and demonstrated variability in the distribution of oils in an industrial watercourse, it is unrealistic to expect short period "spot" or "grab" samples to be reliable within a few parts per million.

2. A chloroform extraction technique for analyzing waters of an industrial watercourse is considered to be superior to techniques which use hexane or carbon tetrachloride.

3. Round-the-clock monitoring is needed in both the sewers and on the River to average out the observed variability and to guarantee the catching of the nuisance large spills which are not likely to be found in a spot sampling program.

4. Sampling techniques for surface oils based on the use of screens and skimmers have limited success, because they become totally fouled with weathered oil which congeals to form a tough resistant grease.

5. During the two-year course of this sampling and identification program, there was a large continuing deposition of oily materials and other pollutants at the bottom and along the banks of the Buffalo River.

6. Surface-active piston films are useful for driving oil films from confined areas, condensing and thickening them, and controlling and directing their motion. Such surface-active piston films are also useful for preventing shoreline impaction of wind-driven slicks and for improving the operating efficiencies of skimmers.

7. Our sampling data show that over the 1969-1970 season, there was a net accumulation of at least 5,000 pounds of oil in the Buffalo River per day and that the major sink of this oil was the shoreline and river bottom.

OIL TRAPPING CHARACTERISTICS OF INVERTED SIPHONS

1. As demonstrated by analysis of samples taken from a full-scale inverted siphon located in the sanitary sewer system in Buffalo, New York, and by tests conducted on 1/24 and 1/12 scale models of this inverted siphon, the inverted siphon sanitary sewer design is nearly 100% effective for trapping surface oils. These oils include those that are constantly discharged into the sanitary sewer, such as cooking oils and greases, and petroleum oils that enter into the sewer as a result of accidental or deliberate discharges from gas stations, railroad refueling operations, and other industrial sources.

2. The inverted siphon sewer configuration has nearly zero efficiency for trapping emulsified oils carried in the bulk waters of the sewer.

3. The oils trapped in the particular inverted siphon investigated during this program were of about 30% biological origin and 70% petroleum origin. Specifically, the petroleum-based fuels were diagnosed as being essentially identical to No. 2 fuel oil on the basis of identical infrared spectra and gas chromatograms. No. 2 fuel oil was routinely used in railroad refueling operations in a major terminal adjacent to the inverted siphon section under study. Such oils were found, by separate sample collection, to be entering the Buffalo Sewer line from an oil sump overflow in the railroad terminal.

4. Most of the oil that accumulated in the vertical chambers of the inverted siphon must have entered the siphon section as floating oils in large spills in order to be consistent with the efficiency of the collection process, as noted above, and with the gas chromatographic analyses of the accumulated manhole contents.

5. It is practical to install oil detectors permanently in the vertical chambers of the inner manholes of an inverted siphon to monitor depths of accumulated oil and to telemeter the data to a remote location via a radio frequency link. It was demonstrated that the oil detection sensors developed under this program are sufficiently rugged to withstand prolonged exposure to the sewer environment.

6. As determined by the limited number of tests performed in the laboratory on 1/24 and 1/12 scale models of the real world inverted siphon studied in this program, the oil trapping characteristics of inverted siphons can be reasonably well scaled using the Froude number.

OIL SKIMMER INVESTIGATIONS

1. Most oil slicks commonly occuring in industrial watercourses, typified by the grossly oil-polluted Buffalo River, are weathered and debris-laden. Often the debris is of large size and separate recovery is required using equipment not compatible with oil skimming units.

2. Drum and belt type oil skimmers fail because of (a) ineffectiveness at the collecting end of the skimmer rather than at the skimming end (i.e., the skimmed weathered oils congeal into a grease which does not flow from the scraping device into collecting containers but instead fouls the scraping implement) and (b) oils fail to flow to the skimmer location after the oil in the immediate vicinity of the skimmer has been removed because weathered oils, and especially those admixed with debris, do not flow spontaneously to recoat the freshly cleaned areas.

3. Weir type (also sometimes known as suction type) skimmers are inadequate because of poor oil-to-water collection ratios and also because of lack of flow of oils from distant areas into the operating region. Lack of stability of weir type skimmers often results in the collection of excessive amounts of subsurface water and only small amounts of surface oil.

4. Spontaneous flow of weathered and debris-laden oil to skimmers can be generated with the use of "piston films" of surface active, nontoxic, ecologically safe agents such as sorbitan monooleate.

5. A major need exists for new collector technology which will allow effective retrieval of those congealed, weathered, and debris-laden slicks which can now be efficiently skimmed--but not collected--by drum and belt skimmers.

6. The best current compromise design for efficiently skimming the oil slicks found on a typical industrial watercourse, such as the Buffalo River, is a suction type skimmer head followed by an oil-from-water separation system, and a separate debris retrieval lift. This is the option selected for the oil recovery boat design developed under this project.

SECTION II
RECOMMENDATIONS

The following recommendations are based on the results of work performed under Federal Grant WPRD 263-01-68 on a "Program for Preventing and Eliminating Oil Pollution of the Buffalo River." The recommendations are grouped according to the major phases of the program.

PNEUMATIC BARRIERS

1. It is recommended that further experimental work be undertaken to investigate modifications to pneumatic barrier design and deployment that will increase their utility. Specific areas to be considered are:

a) Placement of the pneumatic barrier at an angle to the flow to induce a cross stream current to divert oil toward the shore.

b) Placement of a series of jets near, but beneath, the surface of a stream to insure a continual recirculation of oil droplets removed from the subsurface of the oil slick.

c) Modification of the flow field in the neighborhood of the stagnation zone to decrease vertical accelerations and shear forces exerted on the oil slick.

2. It is recommended that a system of two or more pneumatic barriers be designed and installed in the Buffalo River to demonstrate the long-term utility as an effective containment mechanism for occasional oil spills.

DETECTION OF OIL IN SEWERS

1. It is recommended that a program be undertaken to demonstrate the utility of sensors to localize sources of oil and abate the dumping of oil in municipal sewers. A network of 30 to 40 oil detectors, coupled with alarm circuits and sampling devices, should be installed at strategic locations in a metropolitan sewer system with provisions for recording oil concentrations at each detector station, telemetering the occurrence of oil spills to a control center, and taking fluid samples upon detection of a spill. In addition to the ultraviolet transmission sensor, gasoline vapor and other detector devices might also be installed at some of the locations.

SAMPLING AND IDENTIFICATION

1. A hood method and a prism-dip method described in Section IX are recommended for collecting surface oil samples. For thick accumulations of surface oil, where a large amount of debris is present, an in situ freezing technique is recommended.

2. It is recommended that the area of the Buffalo River at the South Park Bridge be considered for stream oxygenation studies. This area of the River was found to have zero dissolved oxygen, very high oil content, and very little sign of benthic or other life nearly all year round.

3. It is recommended that development proceed on an inexpensive disposable environmental quality sampling kit and an on-site buoy mounted monitor, both based on the internal reflection spectroscopy technique.

4. It is recommended that long-term cleanup programs for industrial waterways include scavenging of shoreline deposits using surface-active agents coupled with skimming operations.

5. Follow-on research should be undertaken to compare oil slick samples collected by the various methods used in the Buffalo River (rotating drum, in situ freezing, screen-dip, surface-active hoop, prism dip) so that decisions can be made as to which method can be best applied in a variety of circumstances.

6. Additional investigations of air barrier influence on the adjacent water chemistry should be undertaken, after a careful preselection of the location of the air barriers to provide maximum data yield from the experiments.

7. Further development of surface chemical agents which act as "piston films" to displace, collect, and concentrate oil slicks is recommended.

OIL TRAPPING CHARACTERISTICS OF INVERTED SIPHON

1. It is recommended that a system of oil detectors and telemetering stations be installed at inverted siphon locations in typical municipal sewer systems in order to permit data on depths of oil accumulated in the vertical chambers of the system to be monitored at a central location. Such a system would allow sources of major oil discharges to be isolated. In addition, provisions to pump out the accumulations of oil on a timely basis would prevent large quantities of oil from reaching the treatment plant.

2. Consideration should be given to the construction of an oil storage facility adjacent to an inverted siphon which is known to accumulate large quantities of oil. Oil detectors located in the inner manholes of the siphon could automatically activate pumps that would transfer the accumulated oil to the storage facility.

3. More extensive investigations should be undertaken to determine the limitations of modeling oil trapping configurations. Specifically, the present modeling investigations should be expanded to include a wide range of flow conditions and other oil types, and to determine

the feasibility of separating emulsified oil from the bulk water stream, either by modifying the design of inverted siphons or providing an entirely new design concept. For example, it might be desirable to elongate the inner manhole chambers along the direction of flow to provide a larger oil storage capacity and a longer time for oil in the bulk water to rise in the chamber.

OIL SKIMMING INVESTIGATIONS

1. Continue development of, and eventually standardize use of, nonpolluting monomolecular "piston films" for directing oil towards fixed skimmer locations and thereby thicken the oil for better recovery.

2. Consider the use of monomolecular "piston films" for prevention of "re-slicking" of a given air/water interfacial area after it has been skimmed.

3. Support development of technology to scavenge oil from shorelines, bottom sediments, and bulk waters into oil slicks at the air/water interface which will then be amenable to skimming. Otherwise, routine changes in water flow, water level, and water turbulence (induced by traffic on the watercourse) rapidly repollute areas which have been cleaned of nuisance oil slicks.

4. Establish a large, permanent test facility for evaluating skimmers over a larger range of variables than is possible in a given field location. This facility should include provisions for controlling oil/water temperature and for concentrating oil films in known thicknesses near the skimmer location. A method for inducing accelerated aging (weathering) of a variety of oils to be used in such a facility is also required.

5. Support development of continuously recording oil thickness gauges that can be mounted in front of and behind various oil skimmers to eliminate a portion of the manual labor during skimmer evaluations, especially in the data-taking phase.

6. Encourage the use of statistical methods in the original design and evaluation of skimmer tests so that information on the significance and interaction of the numerous test variables will be obtained at minimum cost.

7. Support the development of certified scaling relationships which, when applied to oil skimming devices, will permit scaled-down versions of new skimmer designs to be tested at lower costs.

8. Continue the development of concepts for an oil/debris removal boat and its associated equipment for oil cleanup operations on industrialized rivers.

SECTION III
INTRODUCTION

In May 1968 the City of Buffalo made application to the Federal Water Pollution Control Administration for a Research and Development Grant for preventing and eliminating oil pollution of the Buffalo River under the provisions of the "Clean Water Restoration Act of 1966". On 24 July 1968, the City of Buffalo accepted a Federal Research and Development Grant (WPRD 263-01-68) for $552,895.00, or 75% of eligible costs, whichever is less. Twenty-five percent of the eligible costs have been provided by the City of Buffalo, the Buffalo Sewer Authority, the County of Erie, and the New York State Health Department in the form of either direct cash contributions or in-kind services. On 18 October 1968 a contract was negotiated with Cornell Aeronautical Laboratory, Inc. (now Calspan Corporation) of Buffalo, New York to provide the research, engineering, and development support required for the program. (Calspan Corporation is the new name for Cornell Aeronautical Laboratory. Because this report was completed prior to the date of our name change (November 17, 1972) Cornell Aeronautical Laboratory nomenclature has been retained in this report.) The overall objective of the program was to prevent oil pollution of the Buffalo River. Specific objectives of the program were:

1) To develop, utilize and evaluate equipment and techniques for containing and removing oil in the River, including floating mechanical barriers and pneumatic barriers for preventing the movement of surface oil; oil skimmers; debris booms; and a boat containing oil and debris removal equipment

2) To develop instrumentation for detection of oil in sewers

3) To evaluate means for trapping oil in sewers and

4) To devise methods for sampling oil to determine its concentration on the river, and to develop methods for analyzing the collected samples to determine their sources

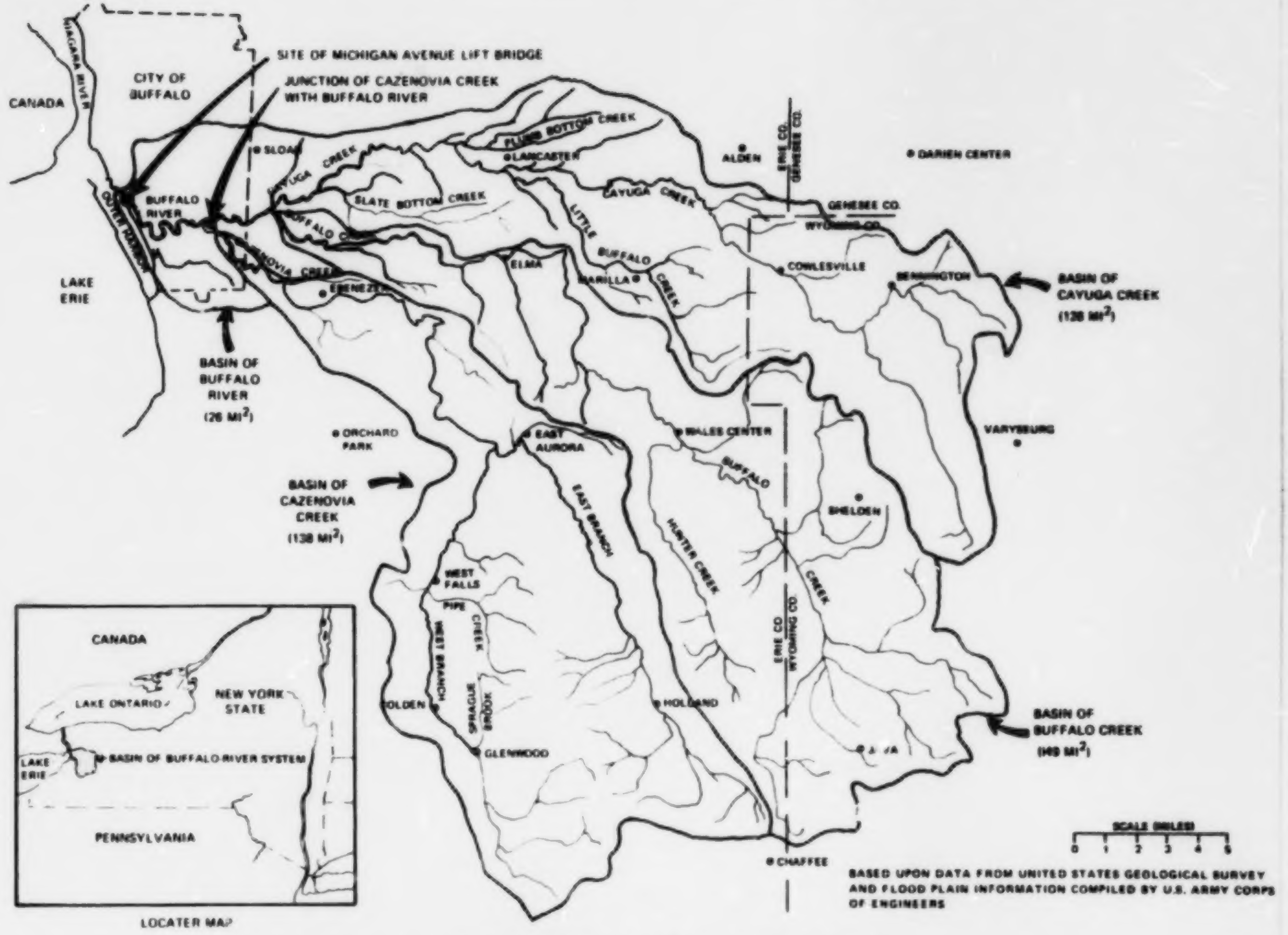
This report summarizes the entire project. Specific aspects of the program are described in detail in four separate topical reports (Ref. 1-4) covering detection of oil in sewers, the investigation of inverted siphons for trapping oil, the evaluation of a pneumatic barrier for oil containment, and oil sampling and analysis for spills in watercourses. The following section of this report presents an overall description of the Buffalo River with emphasis on the oil pollution problem.

SECTION IV
THE BUFFALO RIVER

The Buffalo River is located in western New York State and flows into the northeastern end of Lake Erie just before the starting point of the Niagara River (see Figure 1). It is formed by three major tributaries: Cayuga Creek, Buffalo Creek, and Cazenovia Creek, which extend some 40 miles to the east, southeast, and south of the City of Buffalo. The combined drainage area of the Buffalo River and its tributaries is about 440 square miles and covers sections of Erie and Wyoming Counties which include well-developed suburbs, numerous small communities, and rural areas.

The portion of the Buffalo River which concerns this program begins at the mouth of the river and extends upstream about 6 miles to just above the confluence of Cazenovia Creek as shown in Figure 2. This section of the river is part of a federal dredging project of the Corps of Engineers. The average river width is 275 feet, and the average channel depth is about 25 feet at mean water level. Thus, large lake-going freighters can navigate the lower river up to the first railroad bridge downstream from Cazenovia Creek. The hydraulic properties of the river change quite drastically over the yearly seasons. Beginning in winter, the river and its tributaries from Bailey Avenue to the headwaters are frozen over. Skim and chunk ice are present in the remainder of the river out to the mouth. The sum of the mean annual peak flows for the tributaries approaches about 22,000 cfs, producing currents of approximately 3 feet per second near the mouth. After peak runoff, which usually occurs in the spring, the river becomes relatively quiescent, as evidenced by a 30-year average flow of only 500 cfs. The level and flow of the lower portion of the river are affected significantly by Lake Erie to the extent that during periods of low flow, wastes entering the river in this sector may travel upstream or downstream from the point of discharge.

At least six sewage-treatment plants in municipalities within the river basin bring oils of various types into the river by discharging treated effluents directly into the tributaries. Oil also enters the river through the combined sanitary and storm sewers during periods of heavy rain. While the amount of oil that enters the river from these sources is significant, most of the oil entering the river is discharged by the industries located downstream from the confluence of Buffalo River and Cazenovia Creek (see Figure 2). Heavy industries include a steel mill, an oil refinery, and a chemical plant. The predominant activities on the lower half of this sector of the river are grain storage and milling. The meandering of the river in the industrial sector, combined with the skimming effects of the wind, forms a natural trap for surface oil. Thus, the concentration of surface oil is usually highest in this region of the river, as is the accumulation of oil on the shore.


CANADA
NIAGARA RIVER
CITY OF BUFFALO
LAKE ERIE
OUTER HARBOR
BUFFALO RIVER
SITE OF MICHIGAN AVENUE LIFT BRIDGE
JUNCTION OF CAZENOVIA CREEK WITH BUFFALO RIVER
BASIN OF BUFFALO RIVER (26 MI²)
SLOAN
CAYUGA CREEK
SLATE BOTTOM CREEK
BUFFALO CREEK
CAZENOVIA CREEK
EBENEZER
PLUMB BOTTOM CREEK
LANCASTER
ALDEN
ERIE CO.
GENESEE CO.
DARIEN CENTER
GENESEE CO.
WYOMING CO.
CAYUGA CREEK
LITTLE BUFFALO CREEK
ELMA
MARILLA
COWLESVILLE
BENNINGTON
BASIN OF CAYUGA CREEK (128 MI²)
VARYSBURG
ORCHARD PARK
BASIN OF CAZENOVIA CREEK (138 MI²)
EAST AURORA
EAST BRANCH
WALES CENTER
BUFFALO
HUNTER CREEK
CREEK
SHELDEN
ERIE CO.
WYOMING CO.
WEST FALLS
PIPE CREEK
WEST BRANCH
SPRAGUE BROOK
COLDEN
GLENWOOD
HOLLAND
BASIN OF BUFFALO CREEK (149 MI²)
CHAFFEE
SCALE (MILES)
0 1 2 3 4 5
CANADA
LAKE ONTARIO
NEW YORK STATE
LAKE ERIE
BASIN OF BUFFALO RIVER SYSTEM
PENNSYLVANIA
LOCATER MAP

BASED UPON DATA FROM UNITED STATES GEOLOGICAL SURVEY AND FLOOD PLAIN INFORMATION COMPILED BY U.S. ARMY CORPS OF ENGINEERS

Figure 1 DRAINAGE BASIN OF BUFFALO-RIVER SYSTEM

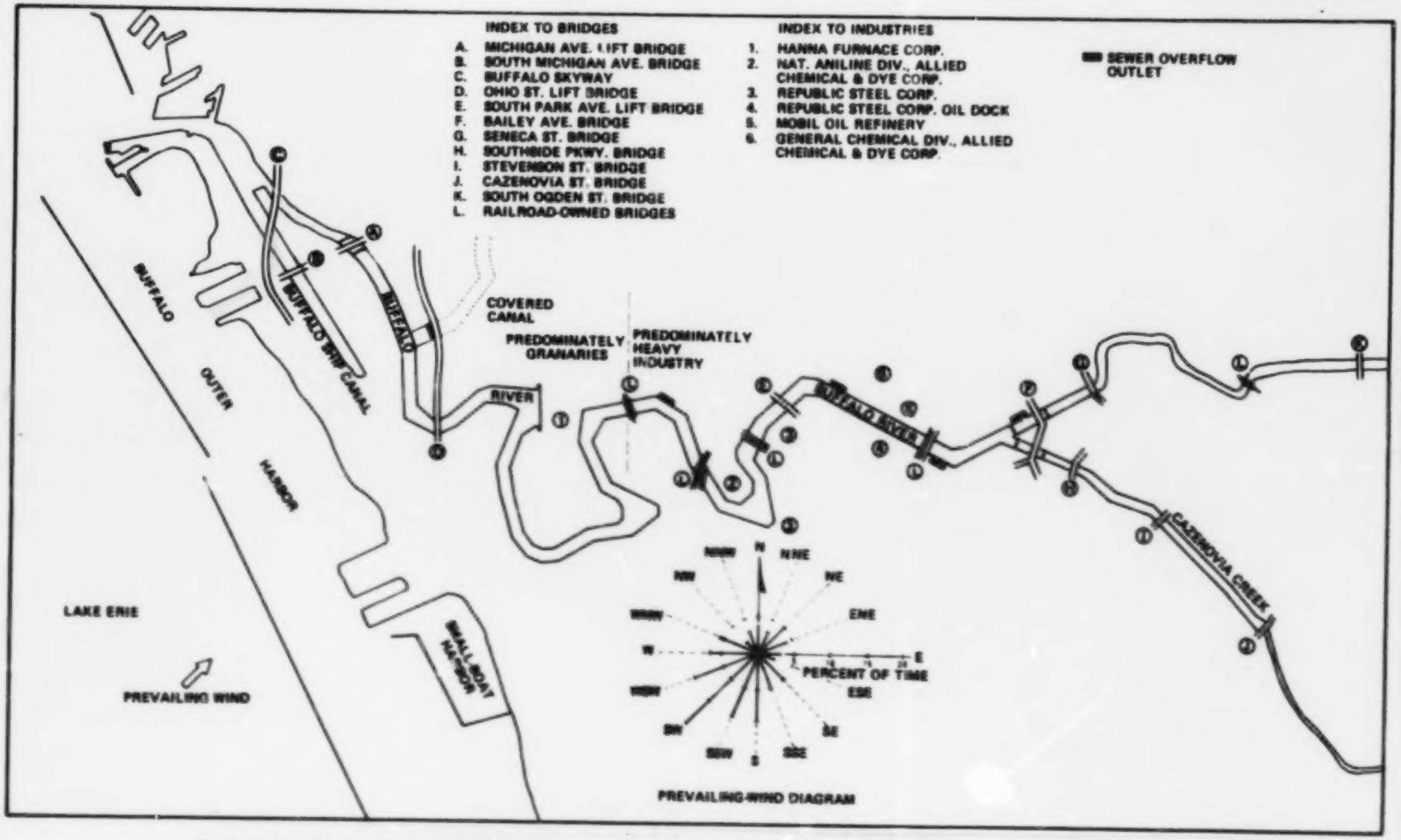

INDEX TO BRIDGES
A. MICHIGAN AVE. LIFT BRIDGE
B. SOUTH MICHIGAN AVE. BRIDGE
C. BUFFALO SKYWAY
D. OHIO ST. LIFT BRIDGE
E. SOUTH PARK AVE. LIFT BRIDGE
F. BAILEY AVE. BRIDGE
G. SENECA ST. BRIDGE
H. SOUTHSIDE PKWY. BRIDGE
I. STEVENSON ST. BRIDGE
J. CAZENOVIA ST. BRIDGE
K. SOUTH OGDEN ST. BRIDGE
L. RAILROAD-OWNED BRIDGES
INDEX TO INDUSTRIES
1. HANNA FURNACE CORP.
2. NAT. ANILINE DIV., ALLIED CHEMICAL & DYE CORP.
3. REPUBLIC STEEL CORP.
4. REPUBLIC STEEL CORP. OIL DOCK
5. MOBIL OIL REFINERY
6. GENERAL CHEMICAL DIV., ALLIED CHEMICAL & DYE CORP.
SEWER OVERFLOW OUTLET
COVERED CANAL
PREDOMINATELY GRANARIES
PREDOMINATELY HEAVY INDUSTRY
BUFFALO
RIVER
BUFFALO SHIP CANAL
BUFFALO RIVER
CAZENOVIA CREEK
BUFFALO
OUTER
HARBOR
SMALL BOAT HARBOR
LAKE ERIE
PREVAILING WIND
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
PERCENT OF TIME
PREVAILING-WIND DIAGRAM

Figure 2 MAP OF LOWER BUFFALO RIVER SHOWING LOCATIONS OF MAJOR INDUSTRIES

Discharge of oil and other pollutants into the river over the years has produced a deplorable situation. In a report issued in August 1968 by the Federal Water Pollution Control Administration entitled "Lake Erie Report: A Plan for Water Pollution Control" (Ref. 5), the Buffalo River is described as follows:

> "The Buffalo River is a repulsive holding basin for industrial and municipal wastes under the prevalent sluggish flow conditions. It is devoid of oxygen and almost sterile. Oil, phenols, color, oxygen-demanding materials, iron, acid, sewage, and exotic organic compounds are present in large amounts. Residents who live along its backwaters have vociferously complained of the odors emanating from the river and of the heavy mosaic of color and patterns resulting from a refinery wastes, raw sewage, and garbage. Thick films of oil are present on the Buffalo River at all times except during flood conditions. In addition to upstream sources, oil is discharged directly to the river by Mobil Oil, Republic Steel, and Donner-Hanna Coke. During times of high flow, these oils, along with the other contaminants are flushed into the Niagara River where they interfere with water intakes, and recreational and wildlife uses."

The Lake Erie Report lists major polluters of the Buffalo River and indicates a discharge of oil into the river exceeding 12,000 lb/day, a figure which is definitely a minimum since it does not include discharges for which no quantitative data were available.

SECTION V
PROGRAM SUMMARY

This section presents a brief overview of the entire Buffalo River program. The major elements of the program and their interrelationship are described. More detailed descriptions of individual elements of the program are described in other sections of this report and complete descriptions of the major phases of the program are described in separate topical reports.

CONTROL OF SURFACE OIL

For years surface oils on the Buffalo River have presented an unsightly mess. Because of the generally low current in the river, winds have a profound effect on the transport of surface oil. The winds, frequently aided by reverse flow of the river induced by a rise in the level of Lake Erie, cause surface oil to enter into Cazenovia Creek and the residential areas of South Buffalo (see Figure 2). The surface oils are ultimately deposited on the shoreline or discharged into Buffalo Harbor and subsequently find their way into Niagara River. An unfortunate incident, which illustrates the magnitude of the surface oil problem, occurred in January 1968 when the surface of the river at the South Park Avenue Bridge (see Index E in Figure 2) literally burned causing severe damage to the bridge.

One phase of the Buffalo River Project was concerned with methods for controlling surface oil on the river. Emphasis was placed on methods for containing surface oils to prevent their transport into the Buffalo Harbor and upward into Cazenovia Creek and on methods for retrieving surface oil. The investigation of these techniques assumed that oil was already present on the river, and was not concerned with preventing discharges into the river; although clearly the most effective way to control pollution is to prevent it at its source. While surface oils can present serious problems as noted in the reference to the fire cited above, the sampling program carried out as part of the Buffalo River Project indicated that surface oils represent but a small percentage of the total oil in the river at any one time, the major portion of the oil being contained in the bulk water. Thus, techniques which are concerned only with surface pollution are limited in the extent to which they can actually prevent the discharge of oil into Buffalo Harbor and Niagara River.

The control of surface oil is commonly achieved by the use of floating mechanical barriers. Such devices are particularly useful in spill situations where their use is required only on a temporary basis. Because surface oil pollution is a persistent problem in the Buffalo River, a permanent system of booms is required. However, the Buffalo River is a navigable waterway from its mouth upstream to the last railroad bridge before the confluence of the River and Cazenovia Creek (see Bridge L in Figure 2). Commercial boat traffic is heavy on the river in summer months and includes ore boats, oil tankers, and grain boats. The placement of floating mechanical barriers across the river would require frequent removal to allow boat traffic to pass. Round-the-clock crews would be required to man the barrier installations. Because of restrictions imposed by the navigational requirements, the use of a pneumatic barrier for containing surface oils was investigated. In its simplest form a pneumatic barrier consists of a submerged pipe having holes at regularly spaced intervals. Air is pumped into the tube and the release of air through the holes causes bubbles to rise above the barrier inducing an upward movement of water resulting in a heave at the water's surface and the formation of upstream and downstream surface currents directed away from the area of the heave. The induced upstream surface current prevents the flow of surface pollutants past the barrier for a limited range of stream velocities.

The Buffalo River Project included laboratory and field experiments to determine the limitations of pneumatic barriers for controlling surface oil in streams and rivers. In the laboratory the effects of nozzle spacing, nozzle diameter, air pressure, air flow rate, depth of submergence of the manifold, and nozzle orientation on the induced surface flow were studied. Data obtained in the laboratory were used as a basis for designing a pneumatic barrier for placement across the Buffalo River at the Michigan Avenue Bridge (Bridge A in Figure 2). In addition to the main air supply tube, flotation tubes were provided to permit the pneumatic barrier to be raised and lowered easily for the purposes of maintenance and change of nozzles. The pneumatic barrier was operated in the river under a variety of conditions to determine its effectiveness for restraining the flow of surface oil in a real environment. A complete description of the investigations pertaining to the pneumatic barrier is presented in Reference 1. A summary of these investigations is contained in Section VI of this report.

For areas of the river where interference with navigation is not a consideration, mechanical barriers for restraining surface oil were employed. Two separate mechanical barrier systems were employed on the upper River at Bailey Avenue: one across the Buffalo River, the other across Cazenovia Creek (see Index F in Figure 2). Later these two separate barriers were removed and a single floating mechanical barrier was installed at Railroad Bridge L of Figure 2. The purpose of these systems was to determine how effectively they could control the transport of surface oil to the upper river region as a result of wind effects. By confining the oil to the industrial section, the deposition of oil to the shore in the upper river region could be minimized. Floating mechanical barriers were also used for containing accidental discharges of oil into the river. The point of discharge was encircled to prevent the transport of oil to other areas of the river.

The program also included the design of a floating debris boom to be used in conjunction with the oil barriers. The design employs steel drums spaced ten feet apart to which are fastened sections of cyclone-type fence. The use of debris booms in conjunction with floating barriers minimizes the wear of the oil barriers by reducing abrasion and punctures.

The use of oil-restraining barriers must be accompanied by oil removal methods. The program included consideration of the important parameters that must be specified in procuring suitable oil skimming or oil pickup equipment. A small test facility for evaluating skimmer performance was set up in the laboratory and several basic skimmer types were used to determine the important performance variables and to devise suitable methods for measuring important performance parameters. A limited evaluation of three skimmer types was made on the river itself.

A trailer was designed and fabricated for transporting floating mechanical barriers rapidly to various sections of the River as might be required for controlling spills. The length of the trailer will permit handling 25-foot sections of boom. A total of 600 feet of barrier can be stored on the trailer.

Specifications were prepared for a debris removal and oil pickup boat that can be used in continuous cleanup operations and in the event of an emergency spill situation. This boat, built by the Grafton Boat Co., has an overall length of 40 feet and a beam of 14 feet. It has a bow-mounted crane for debris pickup and a suction-type oil retrieval system is being procured for removing surface oils from the river.

The Buffalo River Project also demonstrated the utility of surface active agents for controlling surface oil and aiding in its retrieval. These surface active agents form a "piston film" which literally pushes against the surface oil and drives it into selected areas. These agents are particularly effective in driving oil away from shore areas, docks, and pilings.

OIL SAMPLING AND IDENTIFICATION

To determine the distribution of oil on the Buffalo River, an extensive sampling program was initiated. During the spring and summer months surface samples and samples at various depths were collected regularly at up to twelve sites. The deposition of oil along the shore at several locations was determined by placing strips along the shore, retrieving them at regular intervals, and using a solvent to measure the amount of extractable matter deposited on these strips. The bulk water samples were obtained at various depths using a Kemmerer bottle. The surface waters were sampled by a number of methods including a prism dip technique, a hula hoop coated with a surface active agent, a rotating drum sampler, and a screen dip technique. Relatively thick accumulations of surface oil were collected by using a hollow circular cylinder which was lowered vertically into the water. Liquid nitrogen was then poured into the cylinder to freeze the surface sample.

The program included the development of techniques for performing quantitative analyses of the samples collected for the purpose of determining the amount of oil contained in the sample and the type of oil. Hexane, chloroform, and carbon tetrochloride extraction techniques were employed to determine the amount of oil. For determining the types of pollutant present, infrared absorption spectroscopy was used, including the multiple attenuated internal reflection (MAIR) technique. Gas chromatography and atomic absorption spectroscopy were also employed for sample analysis. A complete description of the sampling program and the sampling methods is included in a separate topical report (Reference 2). Additional information is given in Section IX.

SEWER PHASE

Overflow outlets of combined sanitary and storm sewers in the Buffalo Sewer System present a source of oil pollution for the Buffalo River. During times of heavy rain the combined sewer system cannot handle the increased flow of water and the excess is discharged into the Buffalo River. Frequently, large quantities of oil are carried into the river during the storm periods. The presence of oil in the sewers, even during times of normal flow, present potential problems to the sewage treatment plants. To take appropriate measures to reduce the discharge of oil into the sewers to acceptable levels, the major sources of oil must be identified. This might be accomplished most effectively by an in-sewer monitoring system capable of detecting oil. This program included the development of several types of sensors suitable for installation in a sewer environment and capable of detecting oil concentrations of concern. Of a number of basic concepts considered, two having most of the required characteristics were a conductivity sensor and an ultraviolet transmission sensor. Units of both types were fabricated and installed and tested in the sewer environment. In addition, the sensor information was telemetered at programmed intervals to a central station at Cornell Aeronautical Laboratory to demonstrate the feasibility of continuous operation of these devices. The subject of the detection of oil in sewers is covered in detail in Section X and in a separate topical report (Reference 3).

One method of preventing oil in sewers from flowing into the river during times of heavy rains or into the sewage treatment plant would be to provide traps in the sewer lines. It is known, for example, that inverted siphons act as a natural trap for oils and in the Buffalo Sewer system it has been observed for a long time that the inner manholes in inverted siphons accumulate large quantities of oil. Part of the present program involved the investigation of the trapping efficiency of inverted siphons. Field tests on an existing inverted siphon located at Memorial Drive and Gibson Street were carried out. It is in this same sewer installation that the RF conductivity oil sensors were installed for evaluation. The trapping efficiency for bulk water was determined by an extensive sampling program which involved regular collection of samples upstream of the inverted siphon and downstream of the inverted siphon, coupled with measurements of the depth of oil accumulated in the inner manholes of the siphon. The efficiency of the inverted siphon for trapping surface oils was also investigated by taking upstream and downstream samples using a special prism dip technique. For the investigation of other trapping configurations, it would be desirable to conduct experiments in the laboratory with scaled models because of the high cost of installation of an actual sewer system. However, the building of models requires an understanding of scaling laws that would be applicable for the oil/water mixtures. Therefore, the present program included the building and evaluation of two scale models of the inverted siphon at Memorial Drive and Gibson Street. These models were built at 1/12th and 1/24th scales. Experiments at various water and oil flow rates were conducted to determine the applicable scaling laws. A comparison was made of the scaled data for the runs in the 1/24th and 1/12th scale models. Investigations of the trapping efficiency of inverted siphons are discussed in Section XI; additional details are presented in a separate topical report (Reference 5).

SECTION VI
PNEUMATIC BARRIER INVESTIGATIONS

In situations where boat traffic must be maintained constantly, such as harbor entrances and in highly industrialized rivers like the Buffalo River, pneumatic barriers (or air barriers), unlike floating booms provide a potentially effective means for controlling the movement of surface oils without interfering with navigation. The basic mechanism by which air barriers operate is shown in Figure 3. Air is pumped into a submerged tube which contains a series of regularly spaced holes, or nozzles. As the air is ejected, the air jet breaks up into bubbles and the cloud or plume of bubbles entrained in the water causes a local region of decreased density. The positive buoyancy force generated in this region accelerates the air-water plume in an upward direction. As this mixture rises, it entrains additional water into the rising plume, thereby causing the water near the plume to rise. At the water surface the rising column of water divides and creates a flow of water along the surface away from the axis of the plume. It is this surface current produced by the rising air-water plume that is used to counter the flow of surface oils.

In the past, pneumatic barriers (especially portable ones) have been used to contain oil spills. However, very little quantitative data on the operation of these devices were available. Most available information on the operation of pneumatic barriers was derived from tests of this device as a breakwater (see, for example, References 6 through 16). Although this information was useful as a guide in the present study, there remained a lack of data for the operation of a pneumatic barrier in both deep water and in flowing current conditions. Therefore, the first phase of the pneumatic barrier investigations carried out under this program included tests in a water tank at Cornell Aeronautical Laboratory (CAL) to acquire an understanding of the surface current generated from single as well as multiple interacting buoyant air-water plumes. Using the data derived from these tests, a pneumatic barrier was designed, built, and installed in the Buffalo River. The barrier was tested full-scale in the river for a variety of nozzle arrangements and environmental conditions. In the last phase of the pneumatic barrier investigation, a series of tests was run in a dynamic water channel facility at CAL with current capabilities up to 4.5 feet per second.

The following subsections describe the laboratory test procedures and the significant test results, and present the design, fabrication, and testing of the pneumatic barrier system as installed in the Buffalo River.

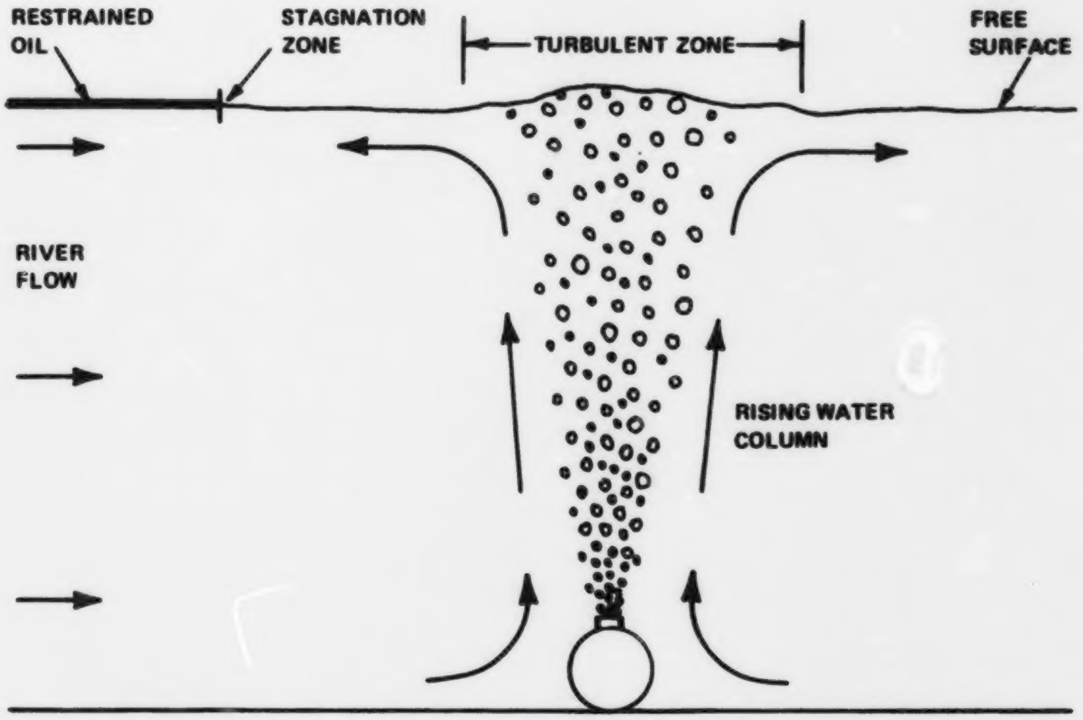

RESTRAINED OIL
STAGNATION ZONE
TURBULENT ZONE
FREE SURFACE
RIVER FLOW
RISING WATER COLUMN

Figure 3 AIR BARRIER EFFECT

INITIAL LABORATORY TESTS

The initial laboratory tests associated with the air barrier investigations were conducted in an experimental test facility located at Cornell Aeronautical Laboratory. The facility consisted of an in-the-ground tank 60 feet in length, 15 feet wide, and 15 feet deep. The objective of the initial tests was to study the surface currents produced by buoyant plumes formed by the ejection of air through single and multiple orifices beneath the water surface. Specifically, the effects of orifice diameter and spacing, direction of the orifices, submergence depth, and air supply pressure on surface heave and plume form were investigated. For the first series of tests a 4-foot length of 3-inch steel pipe served as an air supply manifold. Air was supplied by a 27.5-cfm compressor capable of delivering air at 100 psig. In this phase of the experimental program, tests of single 1-mm, 2-mm and 3-mm diameter nozzles, as well as multiple arrangements of 1-mm and 2-mm diameter nozzles, were all carried out for manifold depths of 5, 10, and 14 feet. The second series of tests employed an 11-foot air manifold submerged at depths of 10 and 14 feet with 1-mm and 2-mm nozzles spaced at 1- and 2-foot intervals. The configuration for the second series of tests is shown in Figure 4.

Tests using single nozzles of 1-mm, 2-mm, and 3-mm diameters and various applied pressures showed that the induced surface velocity is directly affected by depth of submergence. The relationship between induced surface velocity and supplied pressure for a 2-mm diameter nozzle is shown in Figure 5 for submergence depths of 10 and 14 feet. The increase in induced surface velocity with increasing supply pressure is evident in the figure. At any given supply pressure the effect of increasing depth is to increase the surface velocity. Similar trends were also observed for nozzle diameters of 1-mm and 3-mm. The increase in surface velocity with increasing depth can be related to the fact that for small submergence depths of approximately 5 feet, the flow in the air-water mixture is confined to a small zone of high-velocity fluid which forms a fountain of water at the free surface. For such a configuration there is very little opportunity for an effective transfer of vertical momentum to the water surrounding the air-water column. For larger submergence depths, the initial jet region disperses and forms a rising buoyant plume which permits a longer time for transfer of vertical momentum to the surrounding water. Since surface currents produced are directly related to the vertical momentum imparted to the water by the jet in the plume, one would expect to observe larger surface currents as the submergence depth increases.

To determine the effect of directionality of the jet on resultant surface velocity, an experiment was conducted with a single deflected and undeflected 3-mm diameter nozzle. The deflection cap was placed near the jet outlet and produced a radial outflow from the jet. The results of this test are shown in Figure 6 from which it is clear that there is no effect of nozzle orientation on surface currents produced for depths of 10 feet or greater.

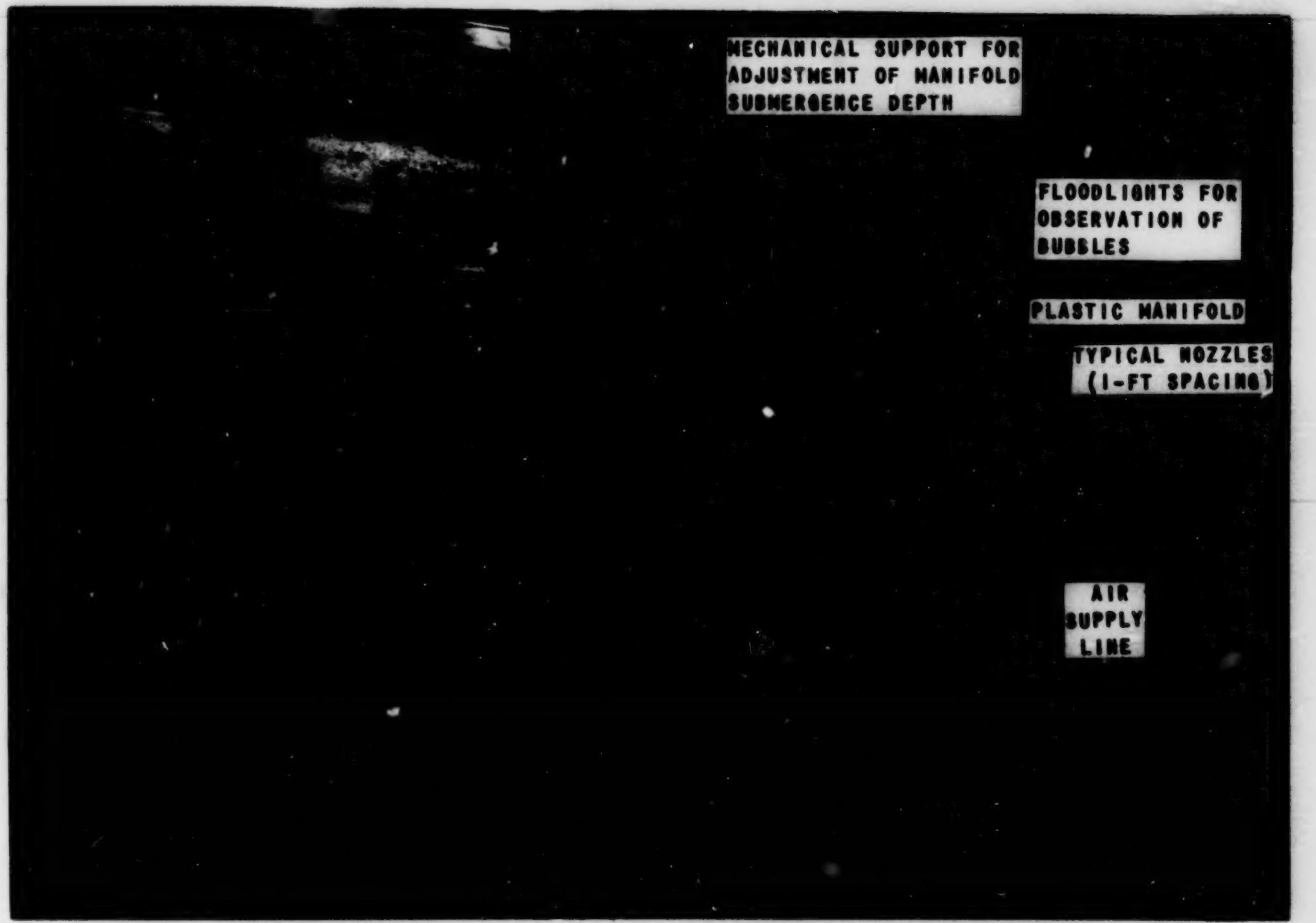

MECHANICAL SUPPORT FOR ADJUSTMENT OF MANIFOLD SUBMERGENCE DEPTH
FLOODLIGHTS FOR OBSERVATION OF BUBBLES
PLASTIC MANIFOLD
TYPICAL NOZZLES (1-FT SPACING)
AIR SUPPLY LINE

Figure 4 TEST CONFIGURATION OF PNEUMATIC-BARRIER [illegible] IN WATER TANK

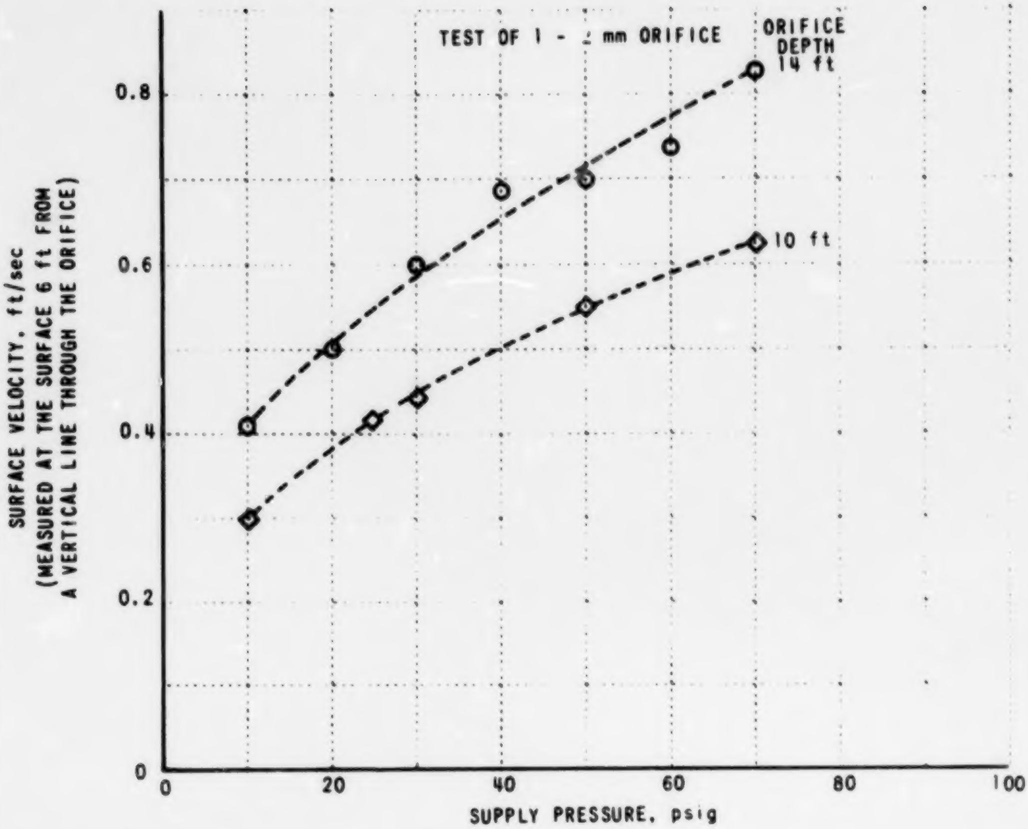


Figure 5 THE EFFECT OF SUPPLY PRESSURE ON SURFACE VELOCITY (TEST OF 1-2 MM ORIFICE)

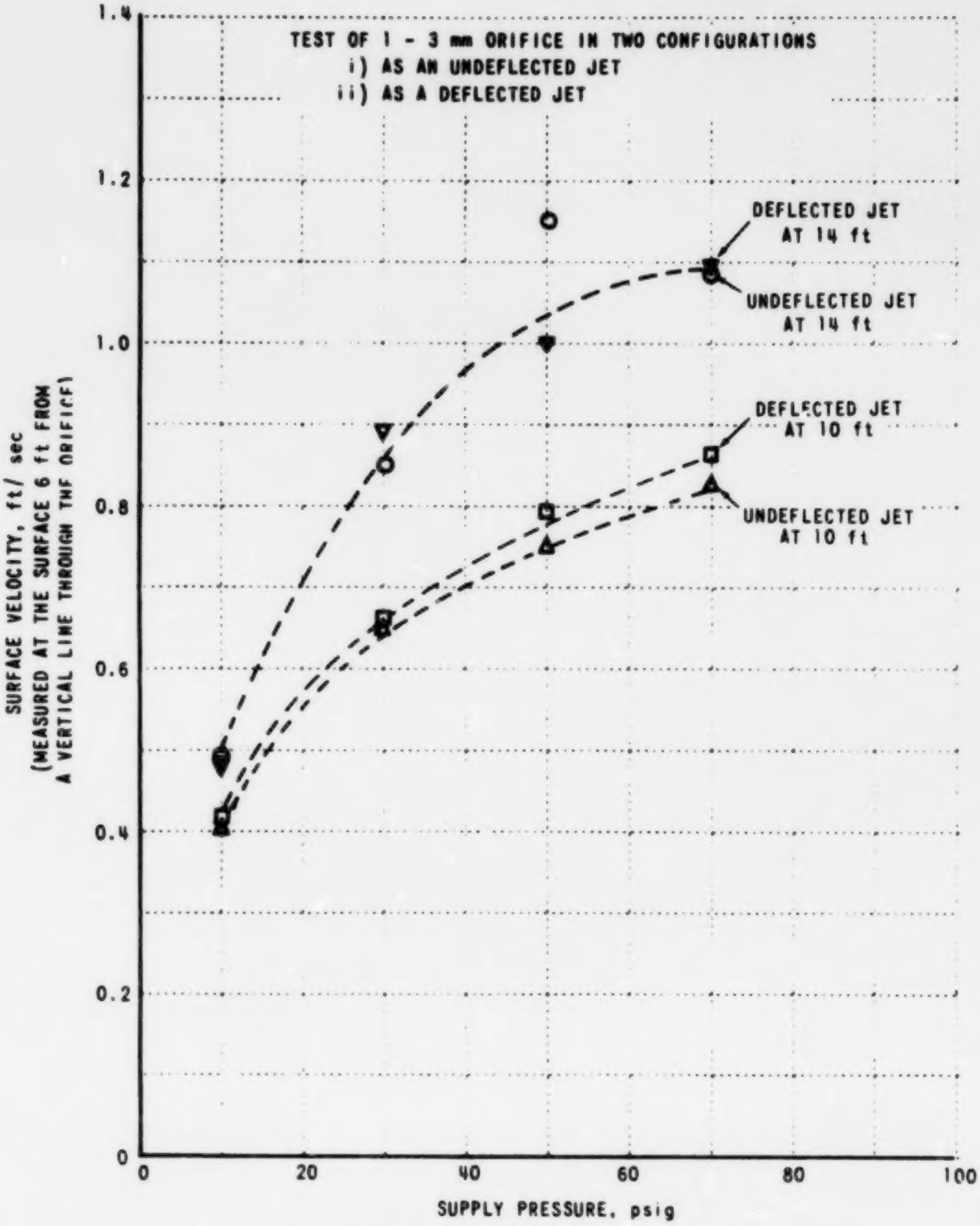


Figure 6 THE EFFECT OF SUPPLY PRESSURE ON SURFACE VELOCITY (TEST OF 1-3 MM ORIFICE)

Since the surface outflow is directly related to the buoyancy force exerted on the air-water mixture, increasing the amount of air placed in a given volume of water should increase the buoyancy force and result in a greater surface outflow. A check of this hypothesis as well as a demonstration that the supply pressure does not have a direct effect on surface current was made by examining the results of representative tests of single nozzles at 14-foot depths. The following listing shows the effect of changing air supply pressure on the magnitude of the surface velocity under conditions of constant volumetric air flow rates.

Nozzle Size (mm)	Supply Pressure (psig)	Volume Rate (scfm)	Surface Velocity (ft/sec)
3	20	8	0.75
2	70	8	0.80

It is observed that changing the supply pressure from 20 to 70 psig has very little effect on surface velocity. In contrast consider the effect of maintaining the pressure constant but varying the volumetric flow rate. The corresponding results are listed below.

Nozzle Size (mm)	Supply Pressure (psig)	Volume Rate (scfm)	Surface Velocity (ft/sec)
1	40	1.4	0.25
2	40	5.6	0.70
3	40	12.6	0.92

The above data indicate that an increase in the air volume flow rate has a much larger effect on the surface velocity than does an increase in the supply pressure.

Tests conducted with two nozzles spaced at 1-, 2-, and 3-foot intervals indicated a significant interaction effect in a multi-jet configuration. Therefore, further tests were conducted to determine the properties of 1- and 2-mm nozzles or 1- and 2-foot spacings over the 15-foot width of the CAL tank using the set up shown in Figure 4. Surface velocities normal to the manifold were measured for several positions along a line parallel to the intersection of the water surface and the vertical plane containing the axis of the air manifold. The results of the tests for 2-mm nozzle diameters at 1-foot spacing are shown in Figure 7. The tests show that for multiple nozzle configurations the surface current changes very little when the emergence depth is increased more than 10 feet. This result is very significant since it implies that the results in tests of water of more than 10 feet in the water tank could be extrapolated to river depths.

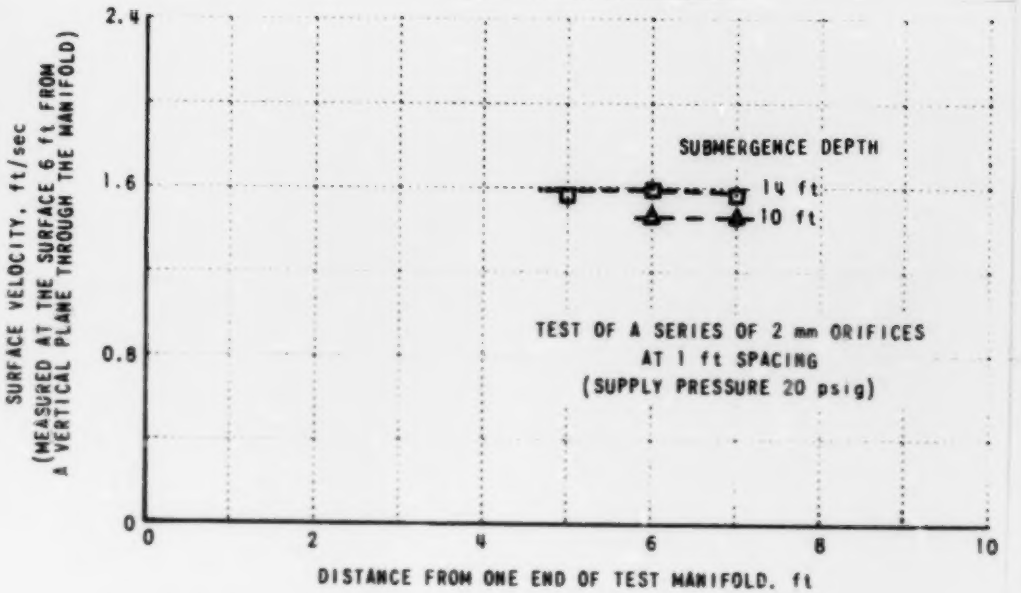


Figure 7 DISTRIBUTION OF SURFACE VELOCITIES NORMAL TO MANIFOLD

IN-RIVER PNEUMATIC BARRIER TESTS

Based on the results of the initial laboratory tests summarized previously, a pneumatic barrier system was designed for installation in the Buffalo River. This subsection discusses the selection of the site, the details of the barrier design, the fabrication and installation of the barrier, and the test results.

Site Selection

The selection of a site for installation of the experimental pneumatic barrier in the Buffalo River was dependent on a number of factors, some of which were not directly related to barrier performance. Among the more pertinent considerations were: (1) availability of an adequate supply of electrical power, (2) easy access to site for maintenance operations, (3) desirability of a location near the mouth of the river so that a maximum amount of oil could be prevented from entering the Buffalo Harbor, (4) favorable position relative to prevailing winds, and (5) availability of vertical bulkheads at the edge of the river upon which the ends of the barrier could be attached. Of these conditions, only Item (5) requires further explanation. For the experimental program, it was desired to minimize any problems that might occur from leakage of oil around the ends of the pneumatic barrier. From water tank tests, it was clear that if a barrier was terminated near a vertical wall in 10 or more feet of water the currents generated near the wall formed an effective seal against end losses. Therefore, since such a solution to the end loss problem was simple and effective, the requirement for a vertical boundary wall for the river channel was incorporated as an important consideration for site selection.

The Michigan Avenue Bridge area was selected as the site satisfying most of the conditions stated above. This site is denoted by letter A in Figure 2. An aerial view of the immediate area around the barrier site is shown in Figure 8. At the selected site, the Buffalo River is approximately 200 feet wide. The water depth at the center of the river channel is about 28 feet. The composition of the river bed, as verified by bottom specimens, consists of hard pan clay across most of the channel. Near the shores a deposit of oil-laden muck or silt was found to overlay the clay. The fact that most of the river bed at the Michigan Avenue site was clay simplified some design considerations since the question of the barrier burying itself in silt was no longer of importance.

Barrier Design

Two major considerations in the design of the air barrier for placement in the river were as follows: (1) Because of the experimental nature

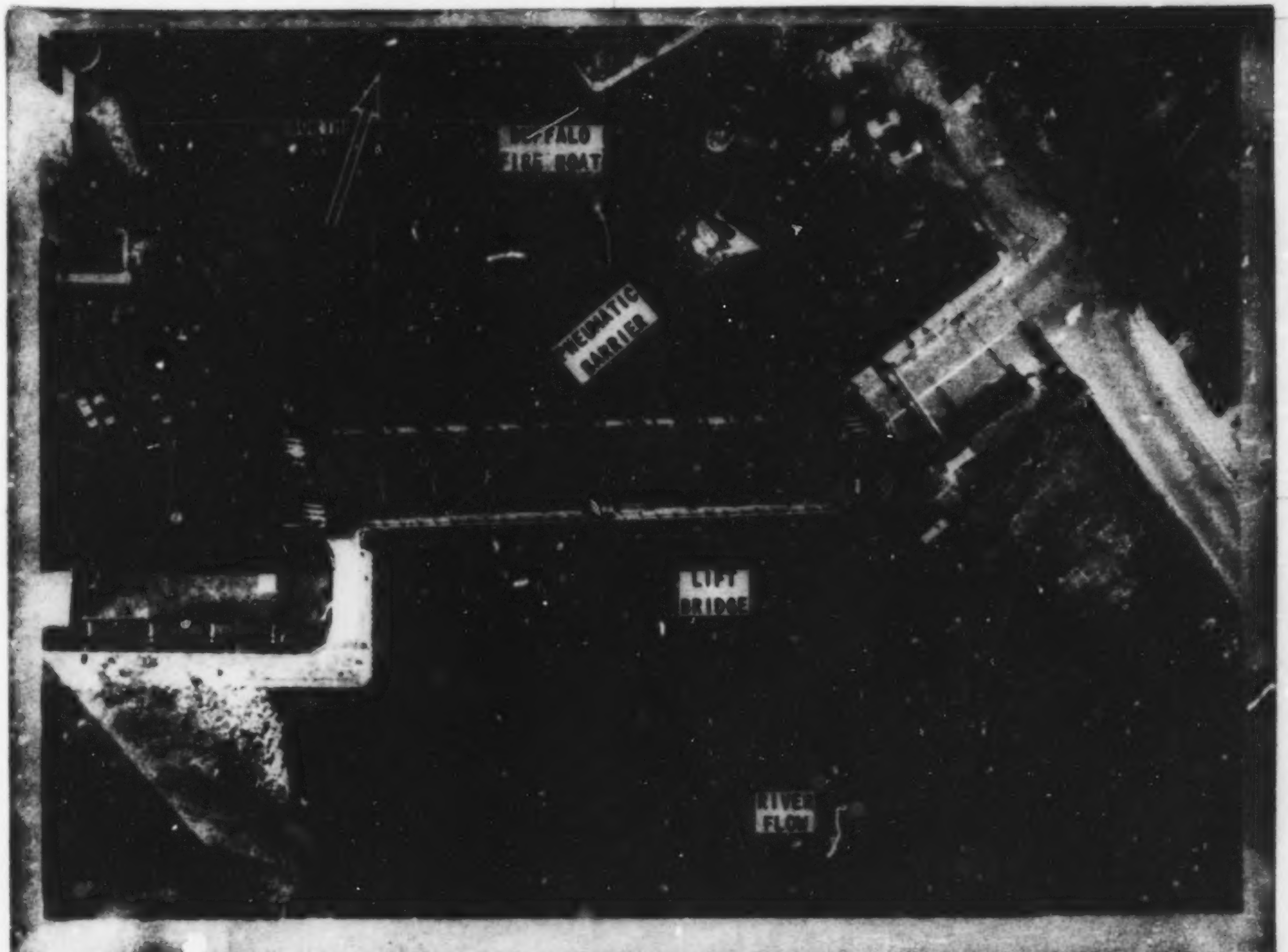

NORTH
BUFFALO
FIRE BOAT
PNEUMATIC
BARRIER
LIFT
BRIDGE
RIVER
FLOW

Figure 8 AERIAL VIEW OF PNEUMATIC BARRIER SITE AT MICHIGAN AVENUE LIFT BRIDGE

of the in-river program it was necessary to provide a convenient means for changing nozzle diameter and nozzle spacing. In addition, the design had to permit the barrier to be raised and lowered rapidly; (2) The anchoring system had to be sufficiently rugged to prevent damage to the barrier during high flow conditions. Both of these desired features were achieved in the final design.

The air supply manifold of the barrier consisted of a 3-inch diameter polyethylene tube approximately 230 feet in length. Although the river is only 200 feet wide at the barrier site, the additional length was required to allow the barrier to be angled with respect to the flow as shown in Figure 8 and to allow the barrier to conform to the bottom contour. Holes having a diameter equal to the root diameter of a 10-32 machine screw were drilled along the length of the air manifold at 1-foot intervals. The nozzles were made from 10-32 stainless-steel phillips-head machine screws into which holes were drilled to provide the desired orifice diameter. In the river test 1-mm and 2-mm orifice diameters were used. A photograph of the nozzles is shown in Figure 9. The screw design allowed the 2-mm and 1-mm diameter nozzles to be interchanged quickly. The spacing between nozzles within 1-foot increments was accomplished by using blank screws, as required.

A flotation system was incorporated into the design to allow the barrier to be raised easily for maintenance and changing of the nozzle configuration. The flotation chambers consisted of two additional 3-inch diameter polyethylene tubes placed on either side of the air supply manifold. The three tubes were fastened together by means of metal clamps and specially cast concrete blocks which also served as anchors to weight the system.

A mockup of the final barrier design is shown in Figure 10. The spacing between the concrete blocks shown in the figure is less than that used in the actual barrier. Drag cables were connected to the concrete blocks so that the force exerted by the flowing water would be taken up by the steel cable rather than by connections to the plastic tubing.

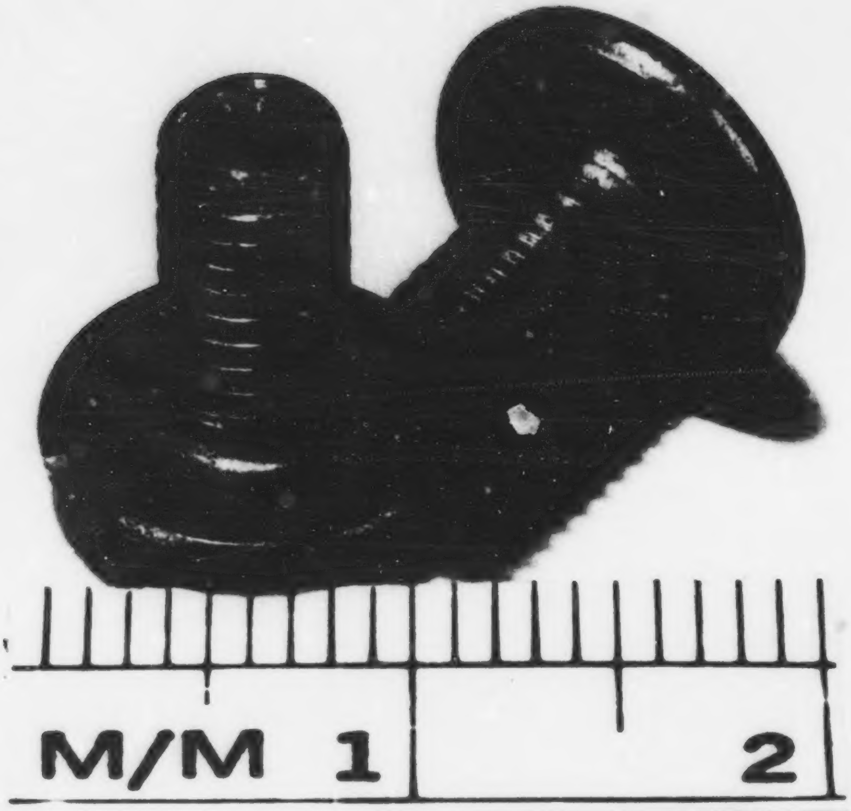


Figure 9 1 mm AND 2 mm NOZZLES

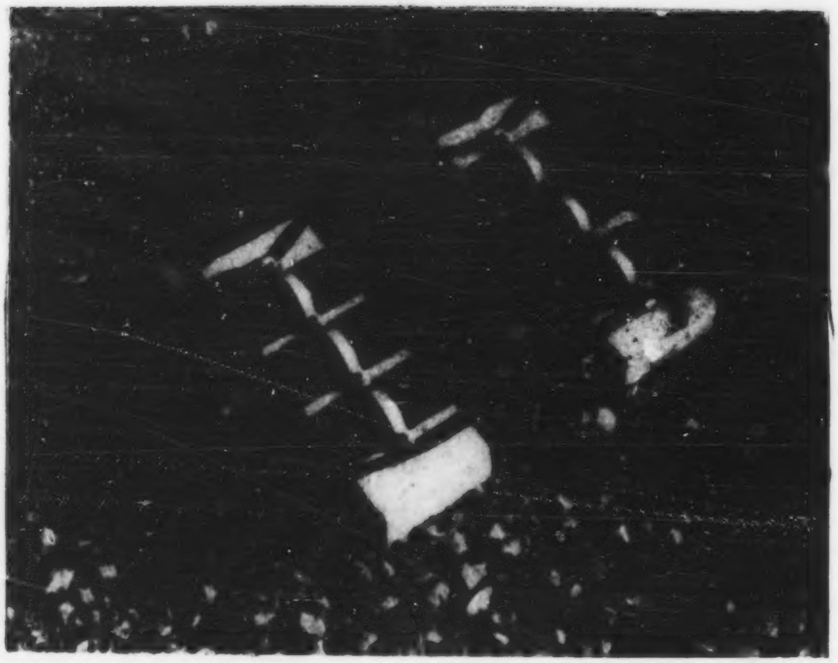


Figure 10 BARRIER MOCKUP

A schematic representation of the pneumatic barrier in place in the Buffalo River is shown in Figure 11. The air supply end of the barrier is shown to the right in Figure 11 and is located on the northeast shore (see the aerial view in Figure 8). The two drag cables extending across the river are fastened to short sections of I-beams, which are in turn fastened to trolleys that ride on vertical I-beams located on either shore. The I-beams are fastened on vertical hingepins, which allow the beams to rotate freely. Details of the shore anchoring system are shown in Figure 12. The positioning winches allow the barrier to be raised and lowered conveniently. Tension in the drag cables is adjusted by means of a separate winch, which is located on the north shore only. The air supply manifold (center tube) extends to the opposite shore and is terminated by a valve, which can be opened to purge the center tube of water during start-up operations. At the end of the barrier opposite to the air supply the outer flotation tubes are connected together. The barrier is lowered by filling the flotation tubes with water. To raise the barrier compressed air is introduced into the flotation tubes to displace the water. The combination of the flotation tubes and the movable pulleys allows the system to be raised or lowered rapidly.

Two 600-scfm, 150-horsepower portable rotary electric air compressors were used to cover the range of supply pressures and volumetric flow rates required for the test program. These compressors were connected to the system so that either or both could be used as desired during the test program. For the majority of the tests, only one compressor was required.

River Test Program

Following the installation of the pneumatic barrier system described above in the Buffalo River in May of 1969, the in-river test program was initiated. Figure 13 shows the surface pattern generated with the barrier in operation. This photograph was taken from the northeast shore. The river flow is to the right in the figure.

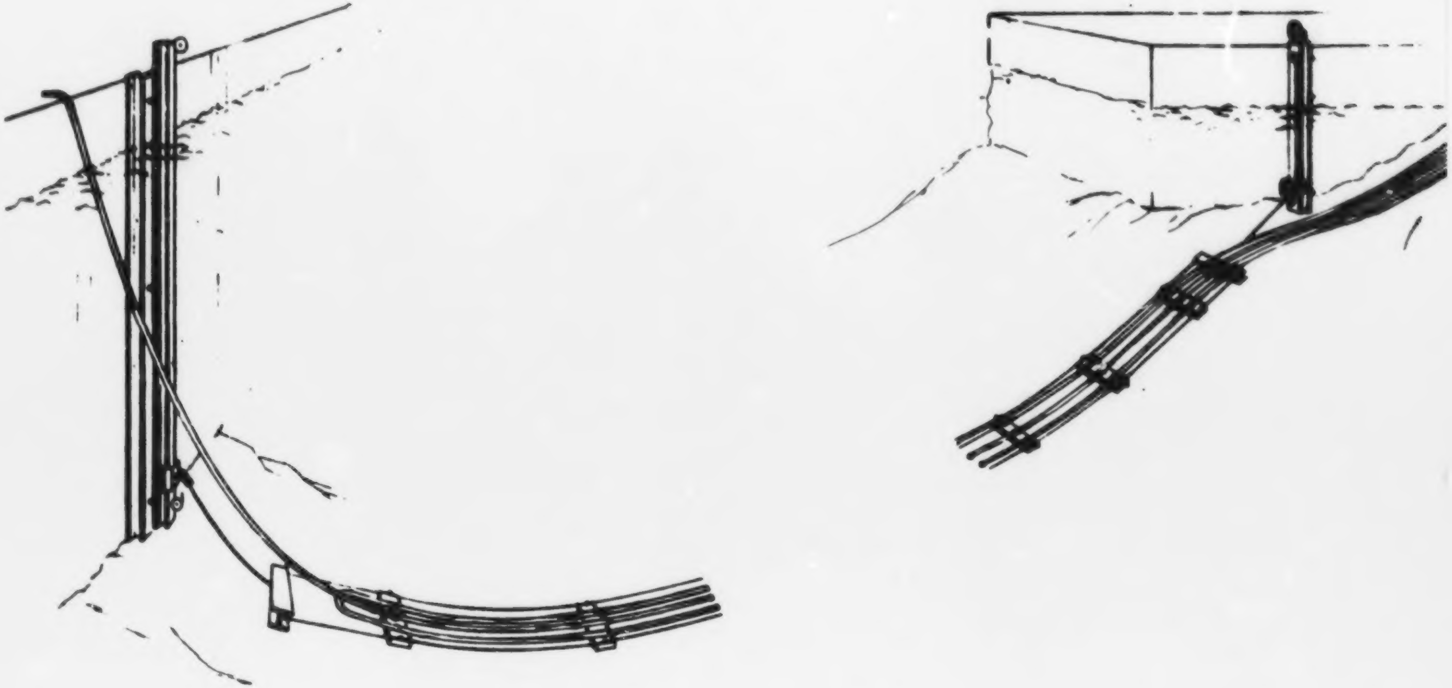


Figure 11 SCHEMATIC OF PNEUMATIC BARRIER IN BUFFALO RIVER

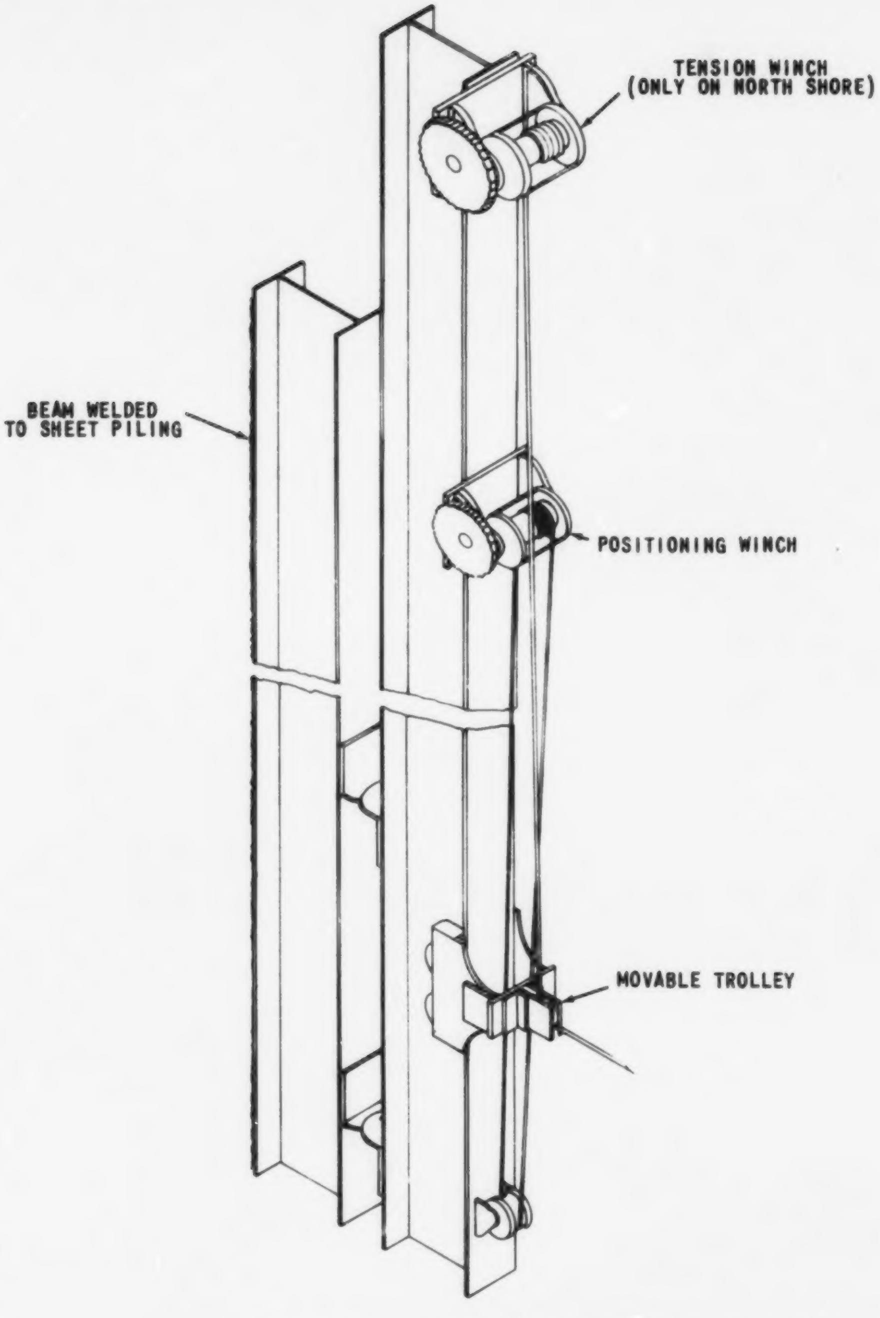

TENSION WINCH (ONLY ON NORTH SHORE)
BEAM WELDED TO SHEET PILING
POSITIONING WINCH
MOVABLE TROLLEY

Figure 12 | PNEUMATIC BARRIER SHORE ANCHORS

Figure 13 OPERATION OF TRIAL BARRIER

During the test program, the positions of the zone of turbulent activity formed by the barrier and the positions of the oil slicks were noted for various orifice configurations as well as for various values of the system parameters. The system parameters of importance were mass flow rate of air, supply pressure, and river velocity. The air supply data were obtained from a calibrated orifice plate. Measurements of the velocity profile of the river, magnitude as well as direction, were made by lowering a Savonius current meter from the bridge. This instrument was ideally suited to measurements of the low river currents existing for much of the time during late spring and early summer. It was noted that turbulent velocity fluctuations within the river cause the current to vary from minute-to-minute. Therefore, velocity measurements were recorded at 1-minute intervals throughout the test periods, which usually lasted between 10 and 15 minutes. An arithmetic average of the measurements was computed and if the series of velocity measurements had a variation of more than 0.1 fps the test was not considered valid.

Although, as noted above, the positions of the upstream edge of the turbulent zone and the slick were recorded for each test, it proved to be more instructive in the course of the analysis to examine the behavior of the difference between these two quantities, denoted by Δ , as a function of the parameters. The reason for this choice is that Δ can be directly related to the condition in which an oil slick formed on the up-current side of the barrier is no longer totally restrained by the barrier. Under this condition one finds that streaks of oil appear on the down-current side of the barrier. The distance between streaks may vary laterally from a few feet up to 20 feet. However, it is emphasized that when this condition occurs only a portion of the oil slick is no longer retained.

For the in-river tests supply pressures ranged from 20 psig to 60 psig. Volumetric air flow rates ranged up to 3.75 scfm per foot of barrier length. For most of the tests the river current was less than 1 fps and for the majority of these tests the current was less than 0.5 fps. A limited number of tests were conducted at currents in excess of 1 fps, the maximum current for any test being approximately 1.7 fps. The variation of Δ with river velocity is shown in Figure 14 for a volumetric flow rate of 3.7 scfm/ft at supply pressures of 30 psig and 40 psig. The curves indicate that Δ decreases with increasing river velocity. Analysis of all the test data obtained shows that at a constant pressure Δ increases with increasing volume air flow rate, although volume air flow rate has less effect on Δ for higher supply pressures than for lower supply pressures. Also, for fixed volumetric air flow rates, changes in pressure have virtually no effect on Δ for river velocities less than 0.5 fps. For velocities greater than 0.5 fps, there is a slightly beneficial effect of increasing supply pressure, that is, Δ increases with increasing supply pressure.

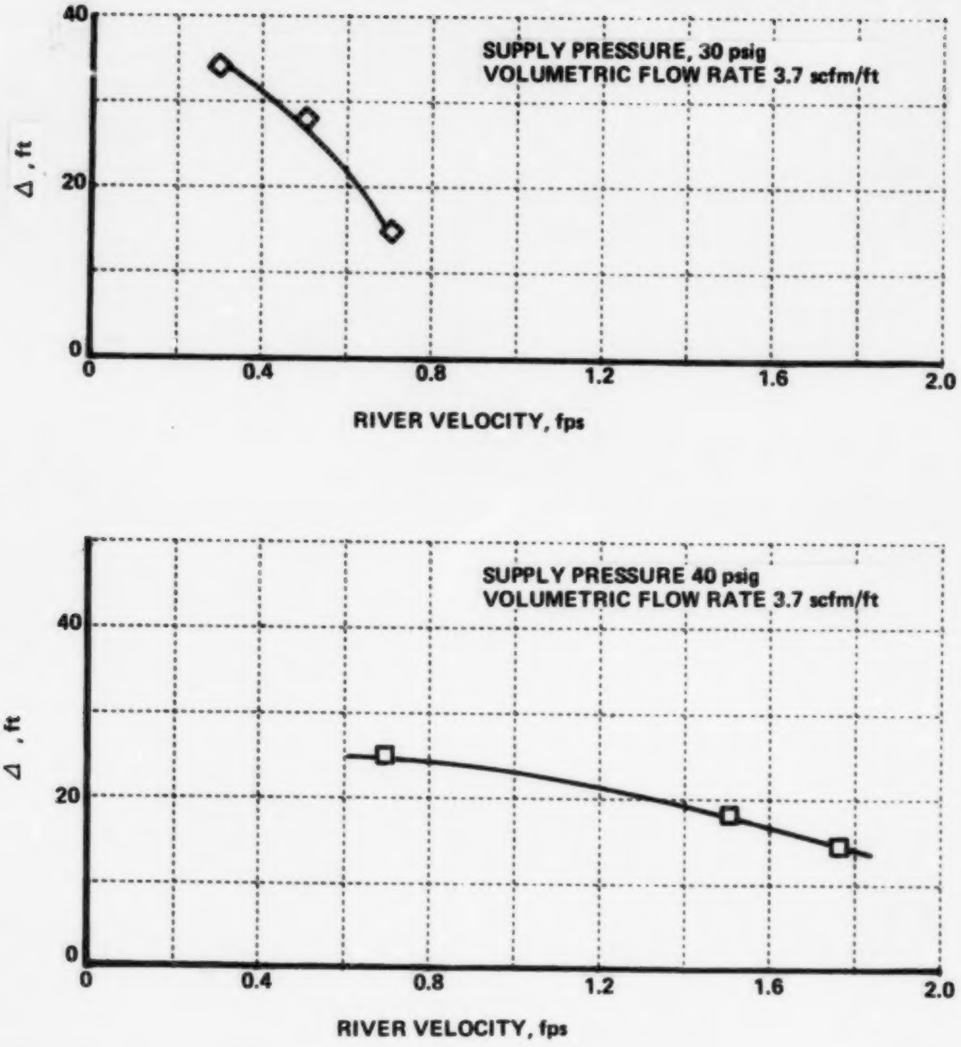


Figure 14 THE EFFECT OF RIVER VELOCITY ON Δ FOR VARIOUS SUPPLY PRESSURES

Another quantity of interest in assessing the overall behavior of the pneumatic barrier is Δ^*, defined as the distance from the mean position of the bubble pattern in the existing current to the mean position the bubble pattern would assume in zero current. The data show that for river velocities less than 1 fps the mean position of the surface turbulent zone varies little with changes in supply pressure or volumetric flow rate. On the other hand, river velocity has a significant effect on Δ^*, as shown in Figure 15.

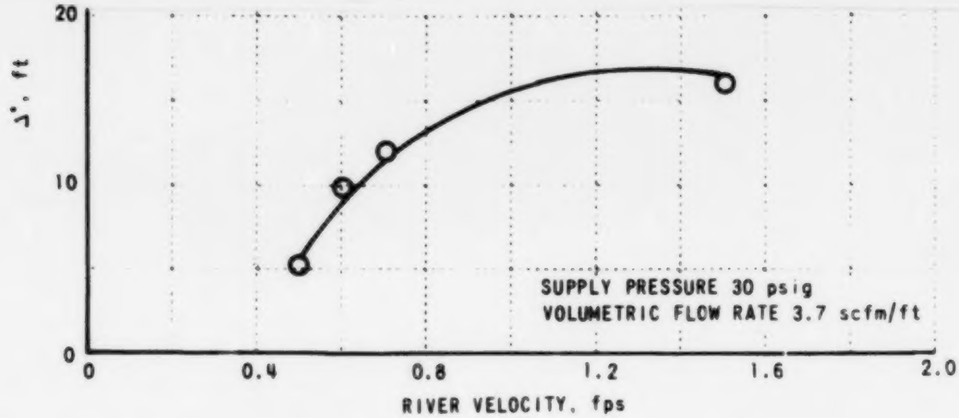


Figure 15 THE EFFECT OF RIVER VELOCITY ON Δ^*

ADDITIONAL LABORATORY TEST PROGRAMS

Only a limited number of in-river tests were conducted with river velocities in excess of 1 foot per second. It was planned to conduct additional tests in the spring of 1970 at higher flows; however, the anticipated higher flow conditions did not occur. In order to determine the velocities at which the barrier failed and to study in detail the failure mechanisms, additional laboratory tests were conducted in CAL's tank test facility which was specially modified to permit tests to be performed in water velocities up to 4.5 fps in one-tenth fps increments. The test section was 45 feet long, 6 feet wide, and 8 feet deep.

The air manifold used to represent a pneumatic barrier was constructed from a 3-inch diameter steel pipe with holes drilled along its length at 3-inch intervals to accept various nozzle configurations. The same types of nozzles used in the river tests (see Figure 9) were used in this portion of the test program.

The objective of the first series of tests was to determine the conditions necessary to ensure the formation of a stagnation zone in the flow. The stagnation zone formed by the stream current and the current generated by the pneumatic barrier was examined for various combinations of stream current, orifice size, orifice spacing, and orifice orientation. The orientations that were examined were such that the orifices were either pointing upward, downward, or horizontally upstream. The stagnation zone was observed visually by noting the position of styrofoam particles floating on the water surface. As for the in-river tests, it was useful to express the result in terms of the quantity Δ , defined as the distance between the stagnation line (edge of oil slick for the in-river tests) and the upstream edge of the bubble pattern. A plot of Δ versus volumetric flow rate is presented in Figure 16 for different stream velocities and different nozzle configurations. The various symbols denote different nozzle configurations as summarized in Table 1. It is clear from the figure and Table 1 that Δ is insensitive to the orientation of the air supply manifold. Since Δ is directly related to the surface velocities generated by the air-water mixture, one can infer that the induced surface velocities are also independent of nozzle orientation. The net effect of this observation is that for conditions investigated, buoyancy forces dominated the jet inertial forces. This indirectly implies that the depth of submergence is not an important consideration in the interpretation of the results. Additional tests showed that the effect of air supply pressure on the position of the stagnation line is small.

Table 1
MANIFOLD CONFIGURATIONS

CONFIGURATION	NOZZLE		ORIENTATION
	DIAMETER (in.)	SPACING (ft)	
A	0.125	1	UP
B	0.125	1	DOWN
C	0.250	0.5	DOWN
D	0.250	0.5	UP
E	0.250	1	UP
F	0.250	1	HORIZONTAL-UPSTREAM
G	0.250	1	DOWN
H	0.080	0.5	UP
I	0.080	0.5	DOWN
J	0.125	0.25	UP

After investigating the capability of a pneumatic barrier to form a stagnation line in a current, the ability of the system to restrain surface oils was examined. To control the area in which the oil was to be spread, as well as to facilitate underwater photography of the oil slicks, two Plexiglas plates, 3/16-inch thick, 12 inches high, and 9 feet long were installed in the test section of the modified tank facility. The plates were placed vertically in the water and separated

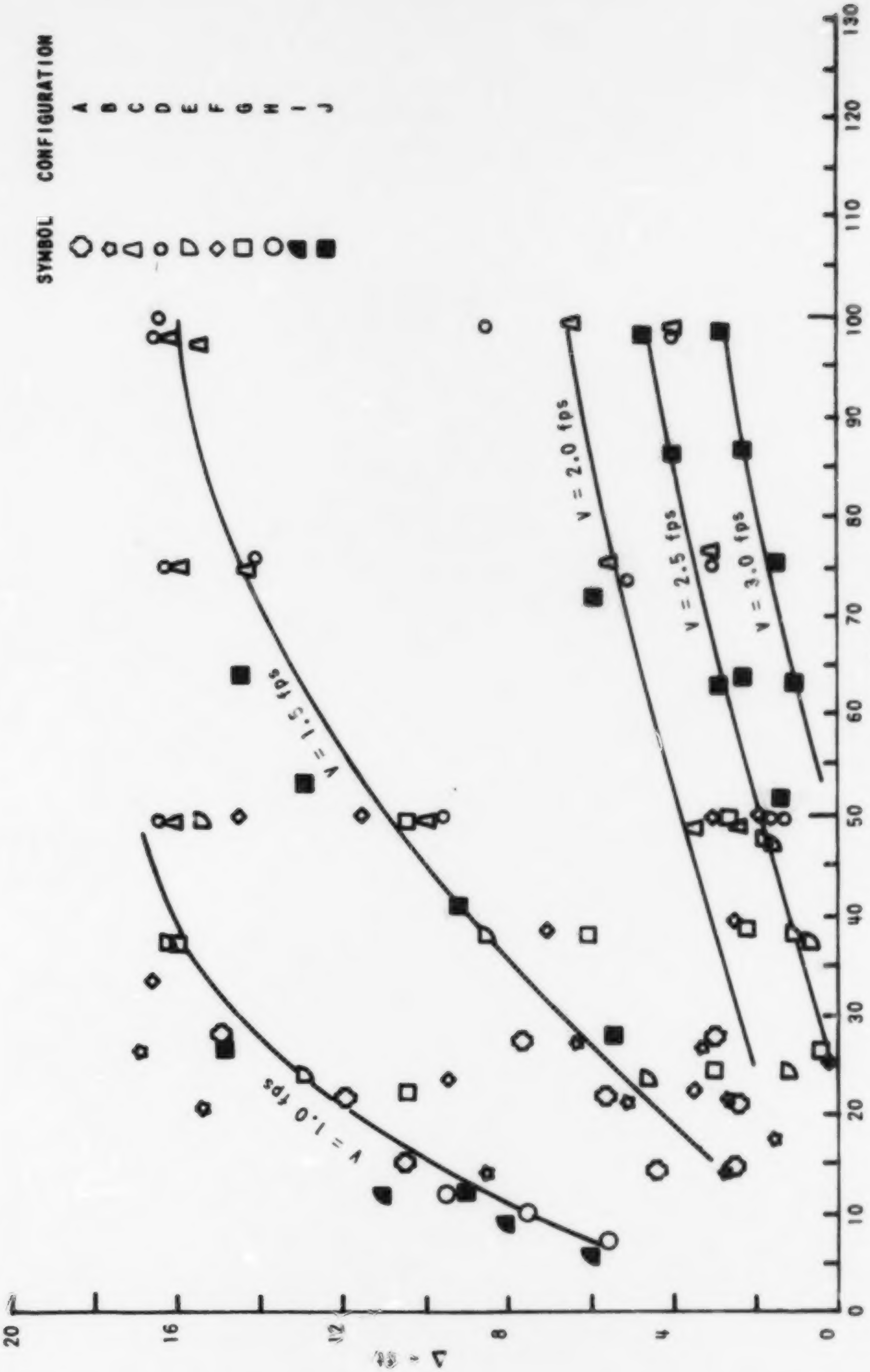


Figure 16 EFFECT OF VOLUMETRIC FLOW RATE ON Δ

by a distance of 2.5 feet. The lower edges of the plates were immersed to a depth of approximately 10 inches beneath the water surface. A photograph of the oil test configuration is shown in Figure 17. Dye tests verified that the flow between the Plexiglas plates was virtually undisturbed by their presence.

For the oil tests a steady current of between 0.3 and 0.5 feet per second was established in the test section. The air supply to the manifold was adjusted to form a stagnation zone within the length of the Plexiglas channel. The current in the test facility was then increased by incremental amounts and corresponding adjustments were made to the air supply to retain the stagnation zone within the length of the Plexiglas channel. The stream current was increased until the oil slick was no longer restrained. A listing of the oils tested, their physical properties, and the current at which serious breakthrough occurred is presented in Table 2.

TABLE 2
CURRENT AT WHICH BARRIER
FAILS FOR VARIOUS OIL TYPES

OIL TYPE	VISCOSITY (Centistokes @100°F)	SPECIFIC GRAVITY (60/60°F)	CURRENT AT WHICH SERIOUS BREAKTHROUGH OCCURS (fps)
No. 2 Fuel	29	0.865	0.7
No. 6 Fuel	970	1.0	1.3-1.5
Bachaquero Crude	324	0.95	0.8
South Louisiana Crude	4.5	0.84	1.0

To apply the results presented in Table 2 for the channel tests to the in-river situation, it is necessary to consider appropriate modeling laws. For a pneumatic barrier a dimensionless parameter known as the Richardson number can be shown to be of prime importance (Ref 17). The Richardson number is the ratio of the buoyancy force induced by the air-water mixture to the inertia forces derived from the freestream velocity. For the laboratory tests used to derive the results presented in Table 2 the relevant parameters were controlled to ensure that the Richardson number was the same for the channel test and the in-river tests. Therefore, one can conclude that the results presented in

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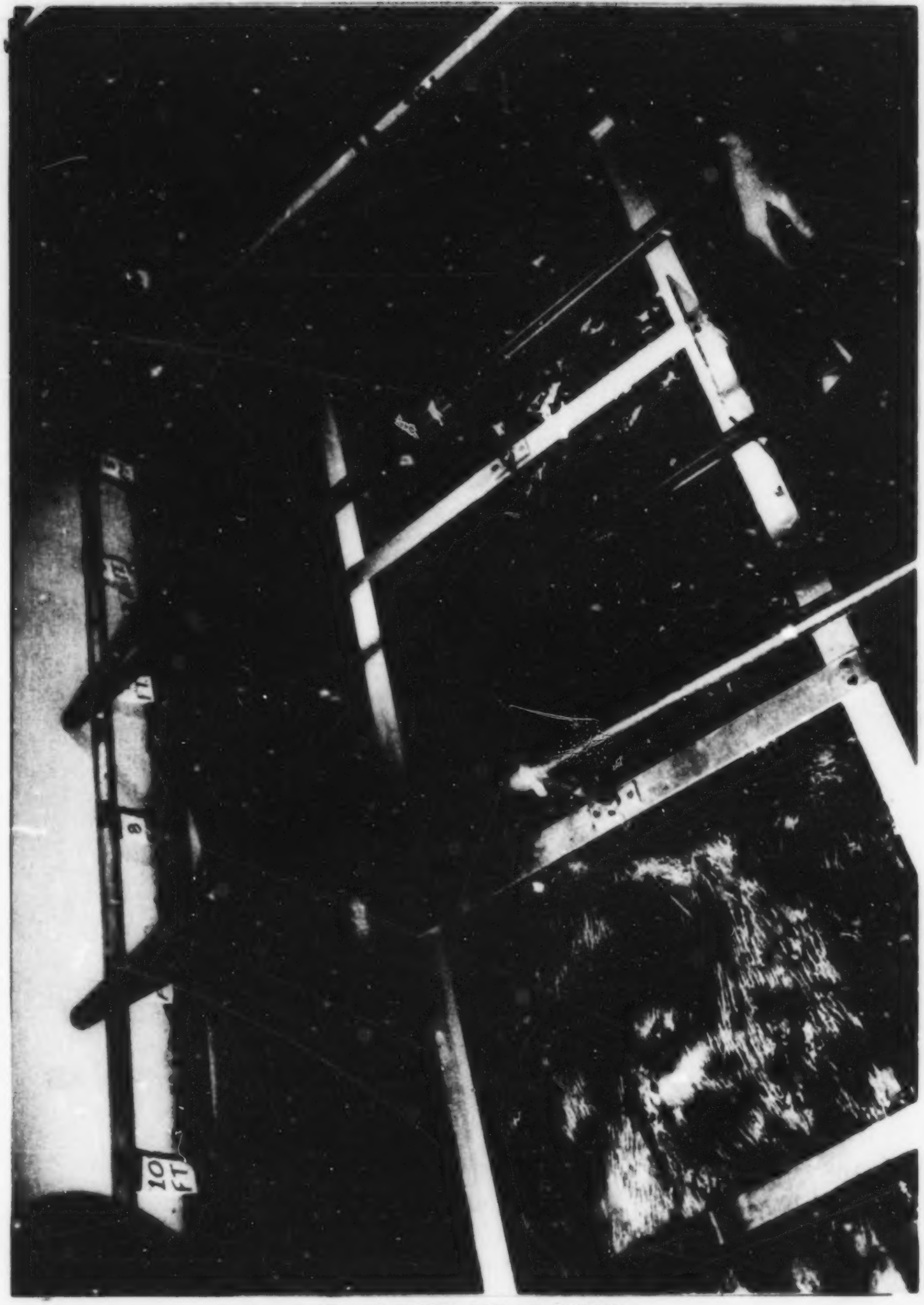

Figure 17 PLEXIGLASS CHANNEL

Table 2 indicate the limitations on a pneumatic barrier operating in the in-river situation.

On the basis of the tests conducted in the channel facility and observations made during the in-river tests, it is possible to identify three modes by which surface oil can pass a pneumatic barrier. The first mode is due to an interaction between vortices shed from a turbulent zone and a restrained oil slick. The second mode is due to the characteristics of the flow field in the vicinity of the stagnation zone. The third mode is related to tearing and subsequent mixing of portions of the oil slick. A detailed discussion of the failure mechanisms is presented in Ref. 1.

POWER REQUIREMENTS FOR PNEUMATIC BARRIERS

From the laboratory investigations conducted in the CAL water channel, as well as the full-scale measurements in the Buffalo River, it is possible to specify the power requirements for an operational pneumatic barrier system. If one assumes that Δ , the distance from the stagnation line to the leading edge of the bubble pattern, must be at least 4 feet then from Figure 16 the airflow rate required for a given stream current can be established. Further, for a given air supply pressure there is a fixed relationship between airflow rate and horsepower. The relationship between required horsepower per foot of barrier length and river velocity is shown in Figure 18 for a supply pressure of 20 psig and a Δ equal to 4 feet. Of particular significance is the sharp increase in required horsepower for river velocities exceeding 2 feet per second. For the Buffalo River, which is typically 200 feet wide over the region of interest in this program, on the order of 200 horsepower would be required for a river velocity of 1.5 feet per second for an air supply pressure of 20 psig. It is to be noted that the required power as derived from Figure 18 is related to the formation of a stagnation zone in the river. This is a necessary, but not a sufficient condition, to ensure the stoppage of oils.

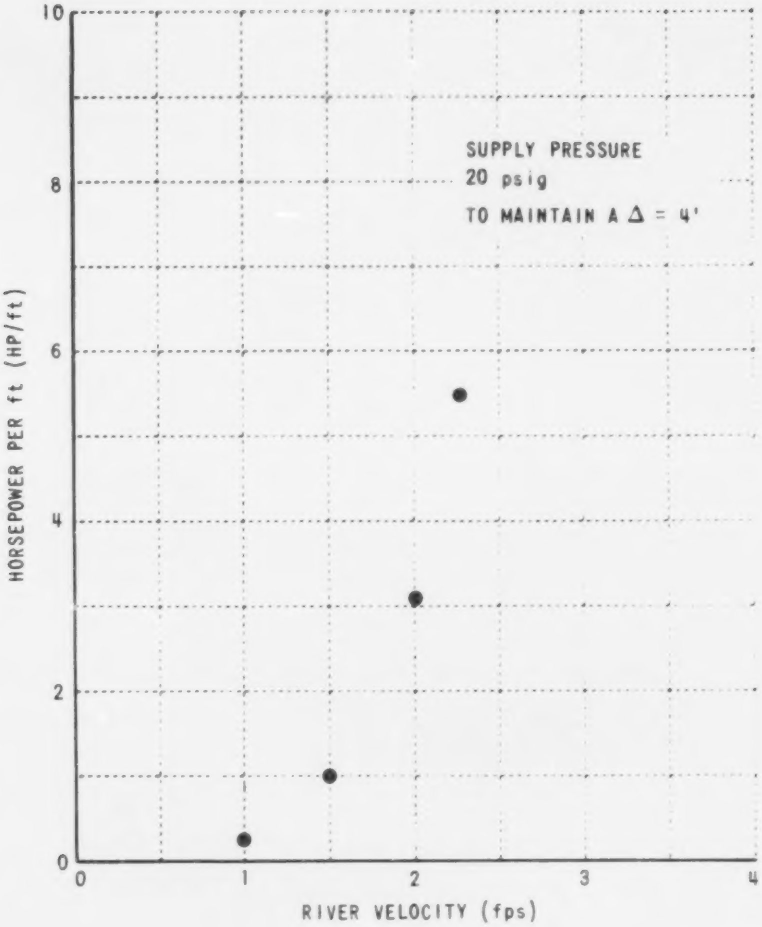

Figure 18 HORSEPOWER VS. RIVER CURRENT

SECTION VII
FLOATING MECHANICAL BARRIERS

In the initial grant application two separate mechanical barrier systems were considered for installation in the Buffalo River. One, referred to as the upper river system, was to be installed across the Buffalo River at the Bailey Avenue Bridge and across Cazenovia Creek, also at the Bailey Avenue Bridge. This system was to contain a combination of oil surface booms and debris booms. This particular location was chosen for the upper river system to prevent wind-driven surface oil from moving upstream into Cazenovia Creek and the upper Buffalo River and, at the same time, prevent oil and debris originating in outlying areas from passing downstream. The lower river system was proposed to prevent oil originating below the confluence of Cazenovia Creek and Buffalo River from reaching the Buffalo outer harbor and the Niagara River. The latter system was to be located as close to the mouth of the River as possible to enable as much oil as possible to rise to the surface for collection. The installation of mechanical barriers in the lower river area was to be considered further only if the pneumatic barrier proved to be ineffective.

This section of the report describes the use of floating mechanical barriers to restrain oil and debris flow in the Buffalo River as carried out under the subject project.

LOWER RIVER SYSTEM

The Buffalo River is a navigable waterway which accommodates large lake freighters that serve the numerous industries located on the river. Therefore, the installation of floating mechanical barriers near the mouth of the river must allow boat traffic to be maintained without interference. In the initially conceived plan, contingent upon the results of the pneumatic barrier investigations, a floating mechanical barrier system was to be installed at the Michigan Avenue Bridge area. This site was originally selected because it is close to the mouth of the river, and it is relatively free of vandalism because of the around-the-clock presence of bridge tenders and the fire crew stationed at the fire boat slip. Three possible designs that would allow the floating mechanical barrier to be removed to allow passage of ships were proposed. The first design consisted of a series of individual sections of commercially available floating booms. One end of the overall boom would be permanently hinged at one shore. The opposite end of the barrier would be fastened in a temporary way to permit a boat crew to disconnect it quickly and tow it to the opposite shore to allow passage of ships. During the shipping season, three shifts would be required to operate the barrier around the clock as required. In the second proposed design, the floating barrier was to be attached to the Michigan Avenue Bridge and operated by the bridge crew as required. The entire boom arrangement would lift with the bridge to permit the oil boom to be lifted out of the water so that when the bridge was raised the lower part of the boom would be at the same level as the lowermost portion of the bridge. The third proposed design consisted of eight 30-foot-long rigid boom sections having springloaded, hinged joints between each section and the ends, but separated at the center span. A pull cable would be attached at each center span end and passed through every second hinge. With the pull cable slack, the two boom halves would be in the extended position via the spring-loaded hinged joints and would abut at the center. Energizing the pull cable would collapse the boom, accordion style, to provide the required navigation opening. Releasing pull-cable tension would allow each boom half to return to its extended position, again via the spring-loaded hinged joints. The pull cable could be energized either by motorized winches or by tieing into the bridge lifting system via a cable-and-pulley arrangement. The automated system would allow operation by the bridge tending crew and would not require additional personnel.

In the course of the overall program an extensive sampling program was undertaken to determine the distribution of oil on the river. On the basis of this sampling program it was determined that very little surface oil normally accumulates near the Michigan Avenue Bridge. Most of the oil in the river flows in the bulk water and most of the surface-borne oils are deposited along the shoreline several miles upstream from the Michigan Avenue Bridge in the area of high industrial activity. Therefore, under normally encountered conditions there would be no need for an oil-restraining barrier at the Michigan Avenue Bridge. For non-normal operations, such as the occurrence of spills, a temporary floating barrier arrangement could be provided near the mouth of the river if required to prevent the passage of surface oil into the harbor and Niagara River, or a pneumatic barrier could be operated using portable compressors. Consequently, no further effort was devoted to the design or installation of the mechanical barrier concepts.

UPPER RIVER SYSTEM

The upper river system, as originally proposed, was to consist of specially designed oil and debris booms to span both the Buffalo River and Cazenovia Creek at the Bailey Avenue Bridge. During our investigations, however, certain results and observations led us to change substantially our original concepts of this installation with respect to both design and location of the booms. The subsections which follow indicate what modifications are recommended and the reasons for them.

Oil Booms

Initially, it was planned to construct the oil booms for the upper river installation of steel tubes. Steel has the advantage of being nearly vandal-proof and the booms could be constructed so as to maintain integrity during high river flow. The weight of steel and the accompanying problems of the installation, however, were major drawbacks, so investigations were focused on the feasibility of installing a good quality commercial oil boom. The Warne oil booms were chosen for installation near the confluence of the Buffalo River and Cazenovia Creek at the Bailey Avenue Bridge. Twenty-five-foot sections of 8-inch diameter booms were purchased as portable booms and were initially installed for testing. In addition, the booms were purchased with fail-safe shear pins provided by the manufacturer to prevent destruction.

Each of the twenty-five-foot long sections of type T Warne boom consists of an 8-inch diameter tube constructed of 1/16-inch reinforced neoprene to which is bonded and riveted a 20-inch skirt of the same material. A bonded tube at the bottom of the skirt accommodates a rubber sheathed galvanized steel ballast chain weighing approximately 4.5 pounds per foot. The 8-inch diameter flotation tube is filled with individual air-filled plastic tubes approximately 2-feet long and 2-inches in diameter. The individual air compartments prevent sinking of the boom in the event the outer casing is punctured.

Upon delivery of the boom sections on September 1, 1969, they were installed across Cazenovia Creek and the Buffalo River at Bailey Avenue, the locations originally planned.

The booms were installed without the protection of an upstream debris boom to evaluate the Warne booms for strength at high flow, ability to retain debris, and problems associated with oil retention. Throughout the initial test period these booms remained intact and retained large amounts of debris. Figure 19 shows the boom sections in place across Cazenovia Creek to be bowed upstream. In dry periods the booms are most frequently bowed in this direction because of the prevailing southwest wind. Note that the debris collected came from downstream. Although the booms have demonstrated an ability to withstand debris, continual battering by debris would undoubtedly cause wear eventually. Therefore, a pair of debris booms for installation across upper Buffalo River and Cazenovia Creek were designed. The specific design features are discussed later in this section.

The sampling investigations carried out as part of the overall Buffalo River project indicated that on a typical November day the thick oil slicks at the booms installed across the upper Buffalo River and those accumulated along the upper river shoreline yielded an average of two pounds per square foot for the pollutant slicks. This value is corrected for the approximately 20 percent water which could be separated from the oily mass in the laboratory, but includes the weight of oil-soaked debris, such as leaves, mixed with the thick grease, oils, and sometimes, dyes. On the average the oil and debris mass contained by those booms extended an average of 6-feet from the booms.

At the Bailey Avenue Bridge, the Buffalo River is 200 feet wide; therefore, the 1200 square feet of trapped pollutants included some 2400 pounds of oil and floating, oil-soaked small debris. If the oil is considered to have an average density of about 8/10ths of that of water,

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Figure 19 WARNE TYPE "T" BOOM INSTALLATION ACROSS CAZENOVIA CREEK AT BAILEY AVENUE

this weight of oil would correspond to about 360 gallons of oil trapped at this one boom alone. Recognizing the existence of other sites with equally thick and extensive accumulations along the upper river, it is estimated that perhaps some 1000 gallons (equivalent) of floating oils, greases, and oil-soaked debris can be trapped naturally and artificially in the upper river area.

The extensive sampling and analysis program carried out as part of this Buffalo River Program showed that large amounts of oil accumulate on the shoreline between the last railroad bridge at the end point of navigation and the Bailey Avenue Bridges, and that most of this shoreline deposit originates from sources downstream of the area. The effect of the strong prevailing winds is to carry the oil generated downstream up into both Buffalo River and the Cazenovia Creek past the Bailey Avenue Bridges. The boom across the Buffalo River upstream of the confluence of Cazenovia Creek could then be eliminated since only a small quantity of oil is coming from upstream sources. However, it would still be desirable to maintain an oil boom across Cazenovia Creek just before its confluence with Buffalo River to prevent wind driven oil from being carried up into the residential areas of South Buffalo. Figure 20 shows the recommended modified boom placement system. It is recommended that the 8-inch diameter Warne booms be used for the indicated oil booms. The debris booms would be specially constructed in accordance with a design prepared by Cornell Aeronautical Laboratory and discussed in the following subsection.

Debris Booms

The debris booms were designed specifically for installation at the locations shown in Figure 20. The width of the Buffalo River just upstream of the Bailey Avenue Bridge is 194 feet; the width of Cazenovia Creek at the same location is 108 feet. The design and placement of the booms were based on several considerations. First, the location of the debris booms just upstream of the Bailey Avenue Bridges permits removal of debris by cranes operating from the bridges. In the actual design of the booms, consideration had to be given to maximum flow rates that might be encountered, and to ease of installing and retrieving the booms, since winter ice conditions at these locations require the removal of the debris booms in the Fall. Another important factor in the design of the booms is that they should be vandal-proof.

For the stress calculations for the Buffalo River boom, a flow of 27,000 cfs was assumed. For the 9-foot depth at this location, this flow corresponds to a velocity approaching 16 feet per second. For the debris boom across the Buffalo River, a 40-foot bow in the boom was assumed. For a uniform load distribution across the width of the river, the boom would assume a catenary shape. (The bow is measured in the direction of stream travel and is measured from the point of anchor of boom to the center.) The total length of the boom for the Buffalo River placement is 214 feet.

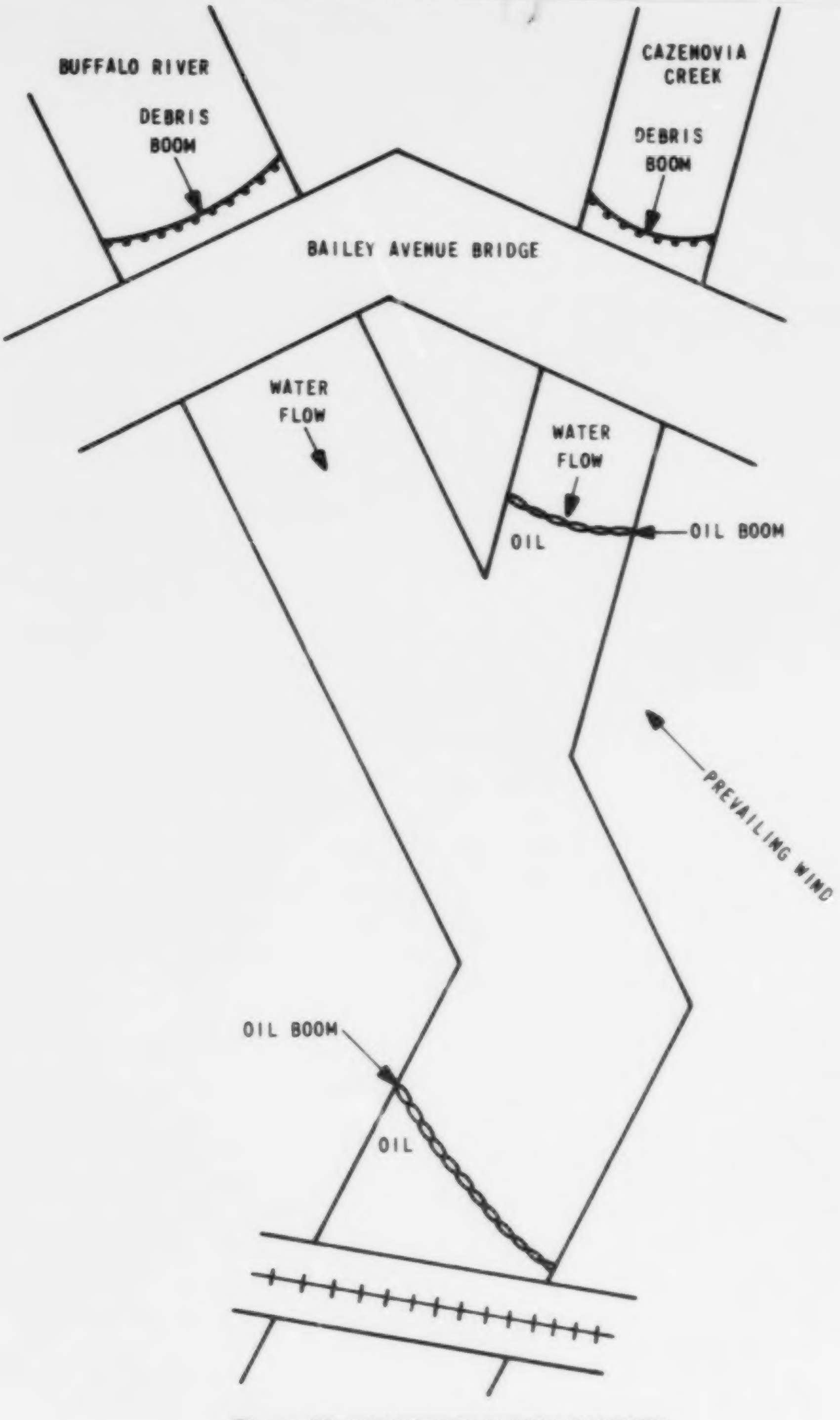
BUFFALO RIVER
DEBRIS BOOM
CAZENOVIA CREEK
DEBRIS BOOM
BAILEY AVENUE BRIDGE
WATER FLOW
WATER FLOW
OIL
OIL BOOM
PREVAILING WIND
OIL BOOM
OIL

Figure 20 MODIFIED BOOM SYSTEM

Basically, the debris boom consists of a 3-foot-high fence consisting of 2-inch mesh made from vinyl-coated No. 6 steel wire. The fence material is suspended between floating 55-gallon drums at 10-foot intervals. The steel drums are filled with 5 inches of concrete for ballast and the remaining void is foam filled to prevent sinking of the barrels in the event of a puncture. The general boom design is shown in Figure 21. The ballast loading for the drums was chosen such that 2 feet of the fencing would be below water level and 1 foot of fencing would be above the water surface. The total drag on the boom is shared by two cables, one located at the top and the other at the bottom of the assembled boom. A slide mount is to be provided on either end of the debris boom to accommodate changes in water level of up to 4 feet. The slide mounts are fastened to the shore pilings by means of a swivel arrangement which allows the "T" slide arrangement to rotate as required for changes in wind and currents. Details of the anchoring hardware are shown in Figure 22.

The same basic design was used for the boom to be installed across Cazenovia Creek with the exception that the total length was 113 feet, allowing a 15-foot bow in the boom. The same cable sizes used for the Buffalo River boom should be more than adequate to handle heavy flow conditions in Cazenovia Creek. At the time of this writing, the debris booms had not been fabricated. Therefore, data are not available on their performance.

Portable Booms

In addition to the permanent booms discussed previously, a supply of portable booms must be kept on hand to cope with accidental spills. For portable applications, 25-foot sections of 8-inch diameter Warne booms are stored on a specially designed trailer to permit them to be transported quickly to any spill site. At the spill site, the individual boom sections can be assembled to form the required length. The ends of the overall boom assembly are then fastened to the shore to provide a closed area for containing the spill. In March of 1970, an underground fuel oil line broke at the steel plant located on the Buffalo River. Oil from the fuel line break spilled into the river and was contained by a number of sections of Warne boom as shown in Figure 23. Some ice remained on the river at that late date as evidenced by the small chunks of ice appearing in the photograph. Also shown in the photograph are two skimmers that were available at the time of the spill incident. The spilled oil was removed by the skimmers and also by straw. The oil-laden straw was removed by a crane.

Sections of portable boom are also to be used on the oil skimming and the debris removing boat which will be discussed in a later section. In the event of a spill, the boat can be deployed quickly to the spill site and the boom sections can be assembled forming the required barrier.

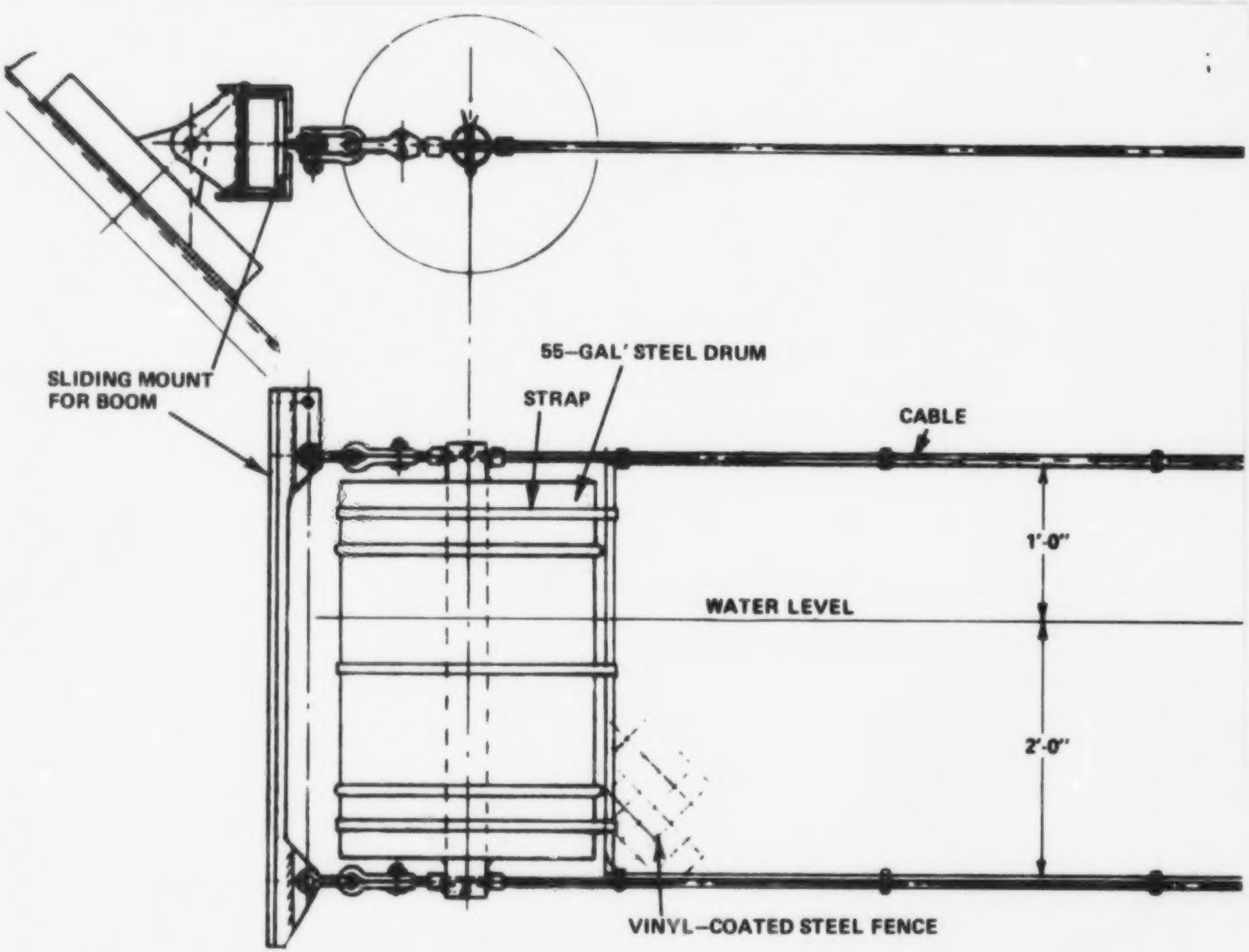
SLIDING MOUNT FOR BOOM
55–GAL' STEEL DRUM
STRAP
CABLE
1'-0"
WATER LEVEL
2'-0"
VINYL–COATED STEEL FENCE

Figure 21 DEBRIS BOOM DESIGN TYPICAL SECTION AND PILING CONNECTION

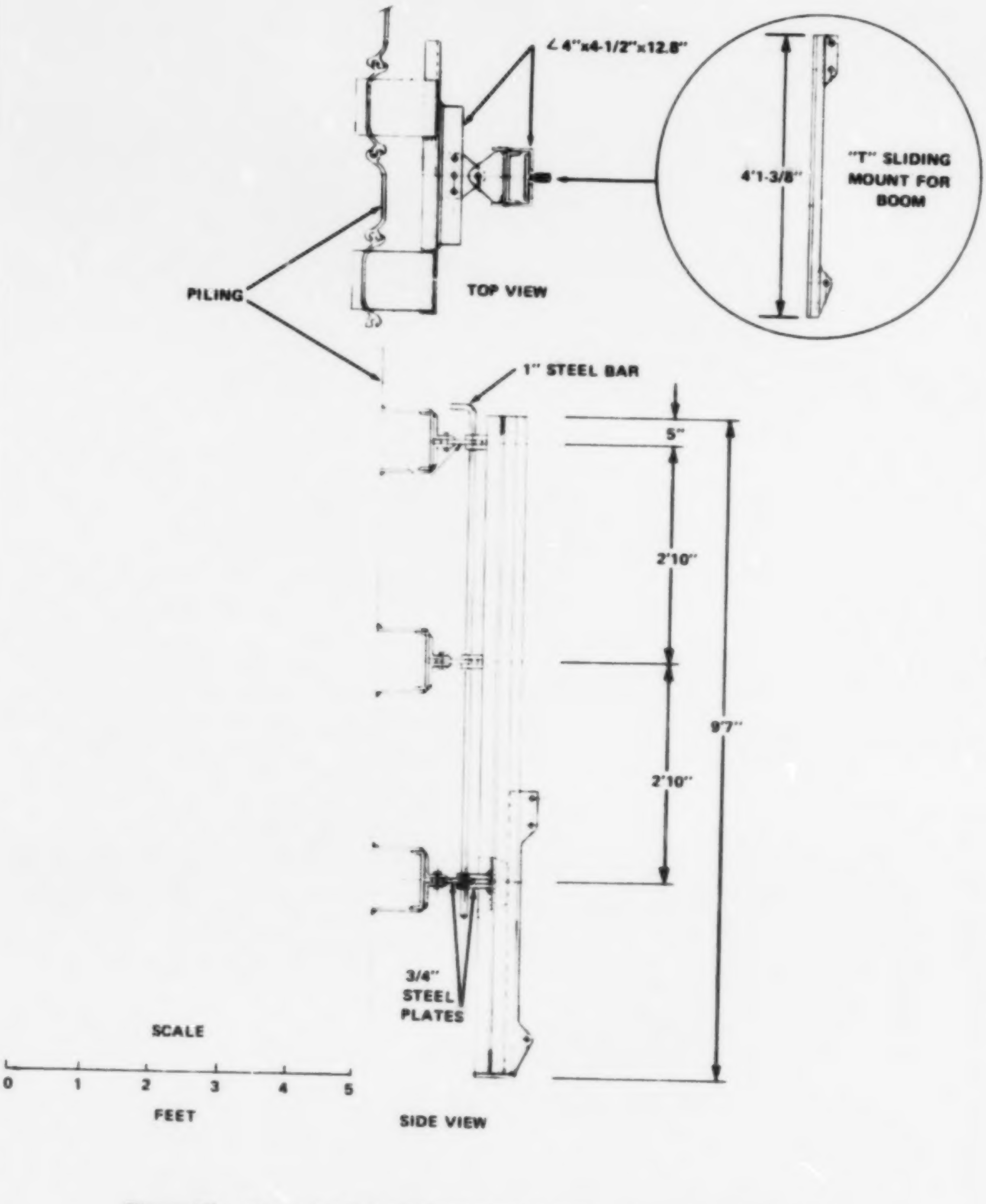
∠ 4"x4-1/2"x12.8"
4'1-3/8"
"T" SLIDING MOUNT FOR BOOM
PILING
TOP VIEW
1" STEEL BAR
5"
2'10"
2'10"
9'7"
3/4" STEEL PLATES
SCALE
0
1
2
3
4
5
FEET
SIDE VIEW

Figure 22 DETAILS OF DEBRIS BOOM END FIXTURE HARDWARE

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Figure 23 PORTABLE BOOMS USED TO CONTAIN SPILLED FUEL OIL

SECTION VIII
OIL SKIMMING

The two previous sections discussed means for containing or restraining surface oil. This section discusses oil skimming, or the process of removing surface oil once it has been accumulated. In general, pneumatic barriers or floating mechanical booms serve no useful purpose unless the oil which they accumulate is removed before it reaches thicknesses which exceed restraining capacity of the barrier system, or before changes in wind or current act to disperse the accumulated oil. Thus, a barrier or boom arrangement must be accompanied by a suitable skimming system. Conversely, it is also generally true that any oil skimming system will operate more effectively if it is used in conjunction with an arrangement of booms to concentrate the oil at the skimmer.

At the inception of the Buffalo River Project and before an extensive sampling program was initiated to determine how oil was distributed over the length and depth of a river, it was planned to install a fixed oil skimming unit at the Michigan Avenue Bridge, suitably located just upstream of the air barrier. As it turned out, an insufficient quantity of oil accumulated at the Michigan Avenue area; and it was deemed inadvisable to install a permanent skimmer at that location. In fact, the general observations made throughout the course of the program, both during the sampling phase and at times when booms were deployed to circle spills, show that because of the varying wind conditions that occur and the highly variable flow in the river no single fixed location would be suitable to operate an oil skimming system in an effective manner. The areas in which surface oil accumulates vary greatly in this river because of the effect of Lake Erie on the flow characteristics of the river. During strong southwest winds, the lake level at Buffalo Harbor rises sometimes in excess of 9 feet under extreme conditions. Thus, for a short time, there can be a "upstream" flow of current in the river. These general observations highlighted the importance of a portable skimming system, which was included in the original program plan. The portable skimming system was to consist of a boat equipped with an oil pickup system and a debris removal crane. Specifications for an oil retrieval boat were prepared and a boat was purchased. The oil skimming boat is described in a later section.

Throughout the Buffalo River Project, attention was focused on the current state of the art of skimmer development in order to determine the most suitable type of unit for application in non-fixed installations. It was found that it is not always possible to put the manufacturer's specifications in the context of the user's requirements. Wind and wave conditions, type of oil, temperature, and oil thickness can be expected to have a strong bearing on the rate at which oil can be picked up for a given skimming unit. Therefore, a small test facility was established under this project to determine the effects of environmental variables, equipment variables, and oil types on the performance of representative types of skimmers. Although this skimmer evaluation effort was rather limited, it provided useful information and a better understanding of skimmer operations. In this effort emphasis was placed on the development and demonstration of methods for evaluating skimmers rather than on complete and quantitative evaluation of the skimmers tested.

LABORATORY OIL SKIMMER TESTS

Test Facility

In keeping with the exploratory and developmental nature of the effort, a readily available minimum-cost test facility was decided upon, even though this would preclude testing for all variables over the full range of interest. A 24-foot diameter, 4-foot high, vinyl-lined, recreational swimming pool was modified by the addition of a central 6-foot diameter core, which helped to provide a nearly uniform circular water flow and also gave support for a 4-foot wide access deck. A photograph of the test facility is shown in Figure 24. The desired currents were generated by means of two 12-volt, fisherman-type trolling motors mounted to the access deck as shown in Figure 25. Operating the trolling motors at 8 and 14 amperes permitted four water velocities to be achieved, ranging between 0.5 and 1.0 foot per second.

The wave-making machinery is shown in the upper left of Figure 24. A 1-1/2-HP hydraulic motor was used to drive an oscillating overhead arm to which a near-vertical plunger was attached; at the bottom of this plunger was attached a 14-inch square plate, which was submerged about 1 foot below the water surface in the neutral position. Both the motor speed and the stroke amplitude were variable over a wide range. In the recorded tests, a plate excursion of 10 inches at an oscillating speed of about 90 cycles per minute resulted in a wave height of 6 inches at the near pool wall (see Figure 26). Under these conditions, the wave height at the skimmers varied from 2 to 4 inches.

Description of Skimmers

In the tests to develop methods for evaluating skimmers, four skimmers of three basic types were used. The skimmers consisted of a drum-type skimmer that was built specifically by CAL as part of the oil sampling program, a variation of a belt-type skimmer, and two weir-type skimmers.

The drum-type skimmer used in these tests is described in the topical report on sampling and identification (Reference 2). Basically, this skimmer consisted of a stainless-steel drum 9 inches in diameter and 24 inches long, which was driven by a 12-volt motor at 14 RPM. The drum was cradled on a U-shaped polystyrene epoxy-cloth-wrapped float so as to submerge the drum by about 1-1/2 inches below the water surface. In operation, the open end of the U faces upstream, and the drum rotates so as to move oil from the water at the upstream side and

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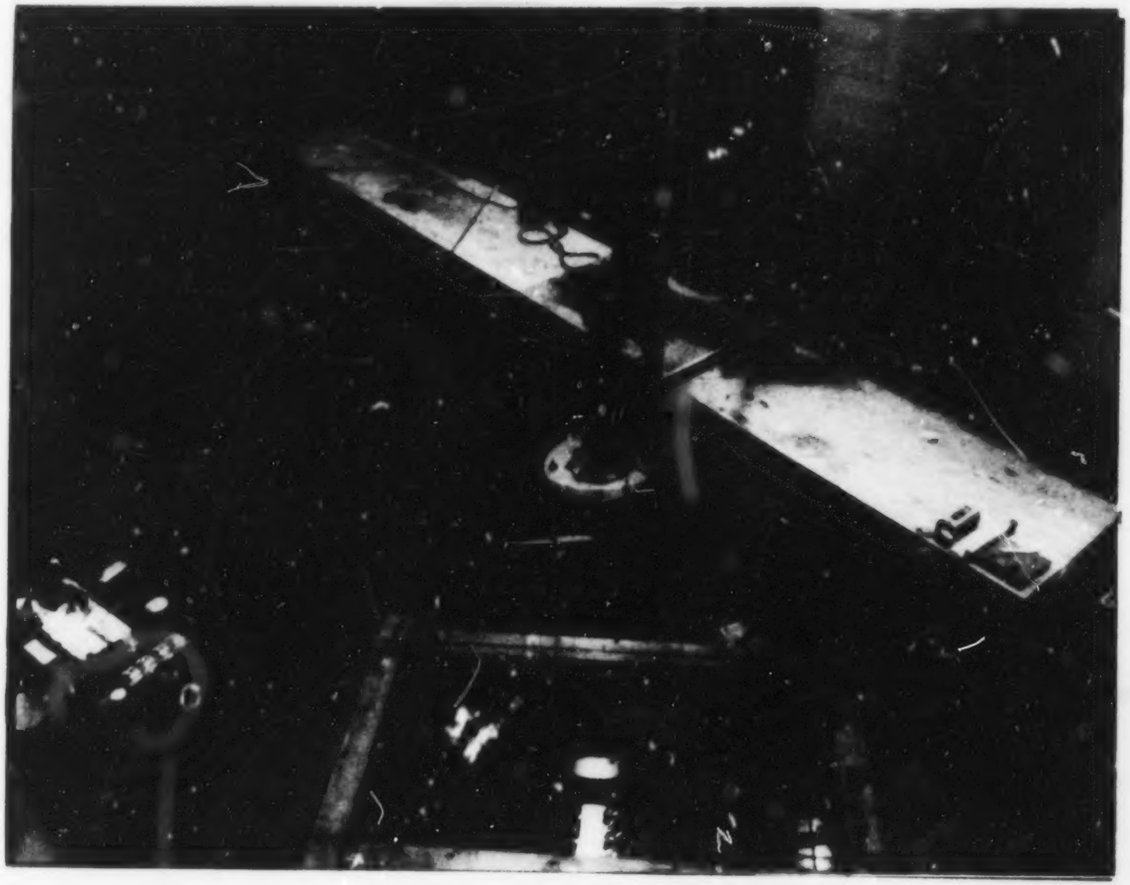

Figure 24 TEST FACILITY – OVERVIEW

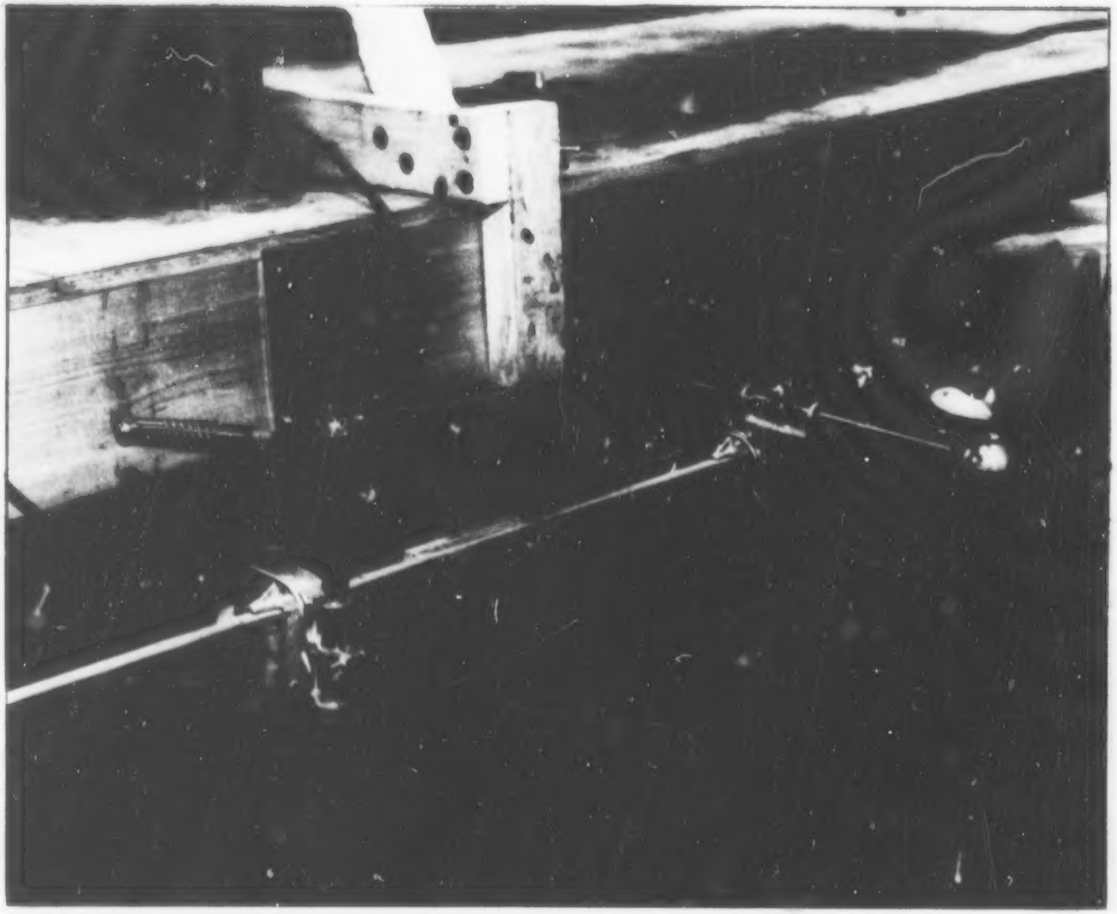

Figure 25 WATER CURRENT GENERATORS

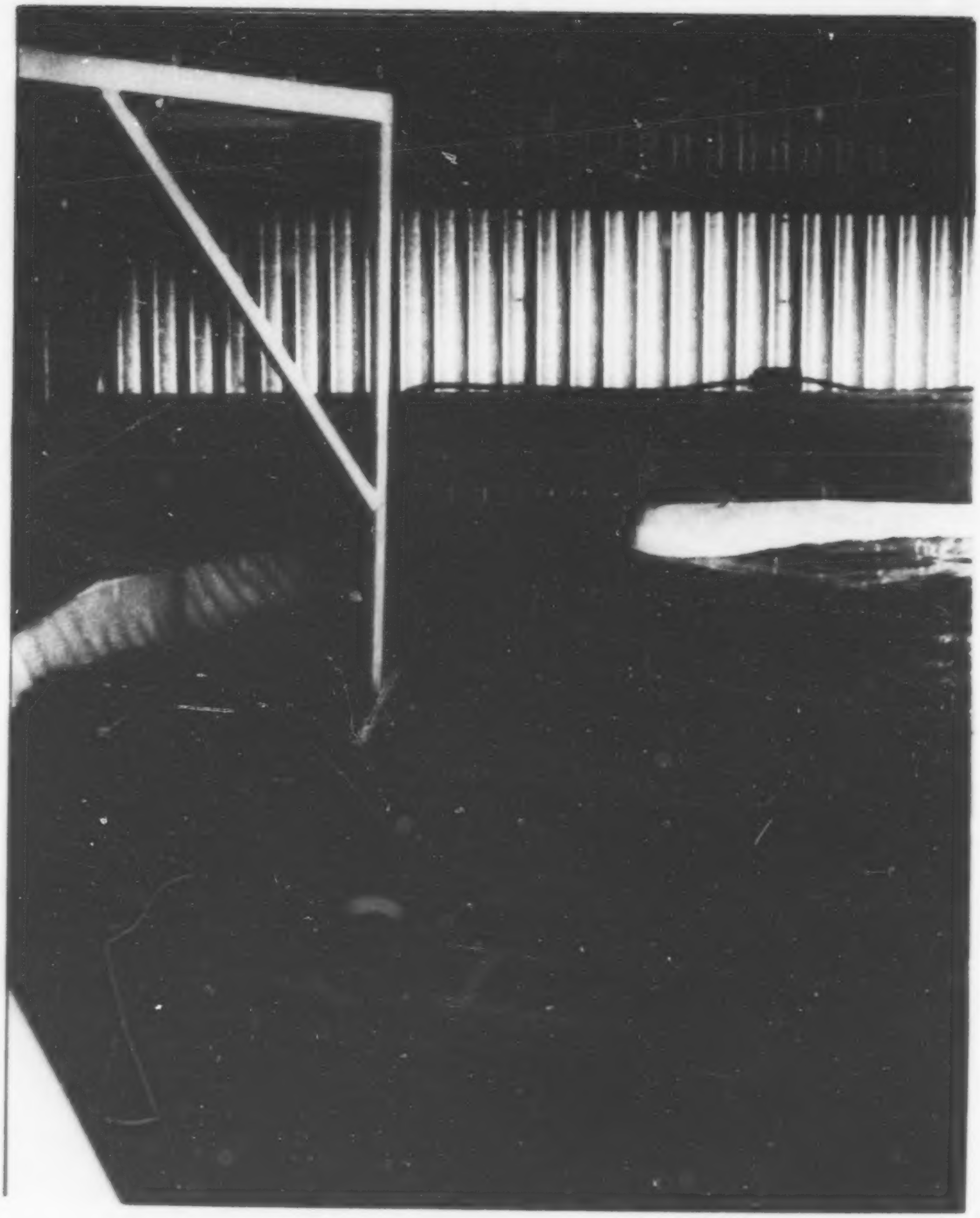

Figure 26 WAVEMAKER

deposit the oil after more than one-half revolution in a trough formed by a rubber-plastic wiper blade and an aluminum pressure bar. The bar is perforated in three places so as to hold three tygon receiving tubes to which plastic sampling bags were attached.

In contrast to other belt-type skimmers which usually take up oil on flat belts or ribbons, the belt skimmer employed in these tests used a long plastic tube, 3/4-inch in diameter, as the oil-collecting element. In this commercially available skimmer, the tubing is driven by a friction drive powered by a 1/2-HP motor, and oil is stripped from the tubing by a helical-spiral wiper. The oil drops into an open, inclined trough and then into any suitable receiver. The tubing moves at a speed of 800 inches per minute.

Sump-or weir-type skimmers have in common two distinct operations: collection of oil and water from the surface through some sort of overflow arrangement; and periodic or continuous removal of the collected liquid. For the tests reported here, a commercially available 40-inch diameter unit was used. In this device, a floating inner unit contains a 3-HP motor and an axial-flow pump. A cylindrical steel bowl is concentrically attached to the float through three vertical adjusting screws which permit the depth of submergence of the upper rim of the bowl to be adjusted. As supplied, the pump on this particular skimmer delivers 200 gallons of liquid per minute through a 6-inch diameter discharge opening. For the pool test, a lower pumping rate was desired. The use of a 3/4-inch diameter orifice at the discharge end of the reducer leading to a 3-inch diameter flexible hose reduced the pumping rate to 100 gallons per minute. The light flexible hose reduced the inherent problem of keeping the skimmer level in operation.

The second sump skimmer used in the test reported here was a floating device that is commercially available as a swimming pool cleaner. An outer bowl is rigidly attached to the pool, and a thin, flat plastic float guides surface liquid into the 4-inch diameter bowl opening. The float is submerged by approximately 1/8-inch. A one-third horsepower motor powers a self-priming centrifugal pump, which sucks liquid somewhat intermittently from the bowl to a 1-1/2-inch diameter hose at a rate of approximately 3 gallons per minute.

Test Methods

The objective of the tests conducted with the four skimmers described above was to develop methods for evaluating the performance of skimmers of these general types under a variety of conditions rather than compare the performance characteristics of the specific units. The conditions varied in these tests were: oil type, oil thickness, water velocity, wave height, debris type, and debris quantity. The types of oil used were No. 2 fuel oil, No. 6 fuel oil, Bachaquero crude, and South Louisiana crude. Oil thicknesses were varied from 0.001 mm to 1 mm. The water velocity ranged from 0 to 1 foot per second, and wave heights were varied up to about 4 inches. Two grades of debris were used: sawdust and a mixture of shavings and sawdust.

Within the scope of the skimmer test program, it was not possible to test all four skimmers under all combinations of the variables indicated above. Considering four types of skimmers, four types of oil, three different oil thicknesses, three different water velocities, two different wave heights, two types of debris, and three different quantities of debris, a total of $4 \cdot 4 \cdot 3 \cdot 3 \cdot 2 \cdot 2 \cdot 3 = 1728$ combinations of test variables are possible. The actual number of tests conducted was on the order of 100, and data were reduced and evaluated for 51 of these.

The data derived from the tests were used to compute four performance measures, namely:

$$\text{Oil Collection Rate} = \frac{\text{Volume of Oil Collected}}{\text{Volume of Oil and Water Collected}}$$

$$\text{Oil Removal Rate} = \frac{\text{Volume of Oil Collected}}{\text{Time}}$$

$$\text{Oil Thickness Reduction Rate} = \frac{\text{Reduction in Thickness of Oil Layer}}{\text{Time}}$$

$$\text{Relative Oil Film Reduction Rate} = \frac{\text{Oil Thickness Reduction}}{\text{Initial Oil Thickness X Time}}$$

The only data required to compute these four performance measures are: the initial and final oil layer thicknesses, the volumes of oil and water collected, and the test duration.

In general, a mixture of oil and water is collected by the skimming device. To measure the volumes of the collected oil and water separately, it was usually sufficient to transfer the mixture to a graduated container and allow it to stand until the oil and water separated by gravity. If the water contained oil in a highly emulsified state, a more accurate measurement of the total oil collected was obtained by a chloroform extraction method, which is a slight modification of ASTM Procedure D1178-60. This analysis method was developed under the sampling and analysis phase of the Project and is described in detail in Reference 2.

For measuring the thickness of oil on the surface of the water, a very simple and rapid measuring scheme was adopted. This method utilizes a glass funnel which is first cleaned in a hot soap solution. After the outside of the funnel is dried, it is slowly lowered into the water, large end first. The oil is driven toward the center of the funnel and eventually collects in the stem. The stem of the funnel is then sealed by finger pressure and the funnel is withdrawn from the water, the oil remaining in the stem. The length of the oil column, multiplied by the ratio of the stem area to the funnel area, provides a measure of the thickness of the surface oil layer. The inverted funnel method was limited to oils that readily spread on water. For non-uniform spreading oils, volume and area estimates were employed.

Test Results

General trends in the data analyzed for the 51 tests are summarized as follows:

(1) The oil collection ratio and the oil removal rate increase with increasing oil film thickness;

(2) The relative oil film reduction rate tended to decrease with increasing oil film thickness (this result is not unexpected since a given thickness of oil removed from the uppermost part of the total layer corresponds to a smaller fraction of the total layer as the layer thickness is increased);

(3) The oil collection ratio of the drum skimmer tended to increase with increasing water velocity, whereas the opposite effect was observed for the belt-type skimmer; and

(4) Water velocity tended to affect the oil removal rates of the drum skimmer and the belt-type skimmer much the same as it affected the oil collection ratios for these same skimmers (see (3) above).

The test data show that the collection ratio (oil/oil and water) can be highly variable for a given skimmer and may range from less than one percent to more than ninety percent. The data also show that the oil thickness ranges at which collection ratios are high differ considerably for different skimmers. High collection ratio is, of course, not equally important in all applications. A prime consideration would seem to be how readily water can be separated from the mixture.

Thus, as the performance of oil-water separators improves, low collection ratios will become acceptable in situations where space and weight capacities allow the installation of separators. However, when space and weight limitations prohibit the use of separators and restrict available storage capacity, high collection ratios are obviously of greater importance.

The test data also show, not unexpectedly, that a skimmer will not necessarily rate high in every respect. For example, a very low removal rate may be associated with high collection ratio as was the case for the belt-type skimmer at thicknesses greater than 0.1 mm. On the other hand, the small sump skimmer had a high removal rate but a low collection ratio in this thickness range.

Qualitative Observations

An important by-product of the reported test activity has been the opportunity to make qualitative observations on skimmers, test procedures and oil behavior.

Such observations are listed below (in no particular order). Some of them have been noted earlier.

- In the presence of debris, the drum skimmer accumulated very little oil in the collection bags. The oil had to be scraped from the blade.

- At the high velocity (1 ft/sec) an oil layer that was much thicker than the original uniform layer accumulated in front of the drum. To some extent this is a peculiarity of the particular drum design used, whose U-shaped float prevents downstream flow of oil that is not taken up at the flow rate. Since both collection ratio and removal rate increase with increasing film thickness, the pecularity of this particular skimmer design enhances performance.

- Wave height measurement may be an elusive problem unless a location far from the skimmer is used for reference and the wave length is constant. The reason is that the skimmer itself has an effect on local wave height. Further, the skimmer motion itself is less than the height of the waves if the skimmer base is longer or wider than 1 wavelength.

- Apparent oil thickness, as measured by volumetric methods (e.g., by the inverted funnel or in graduated beakers) was influenced by dirt, breeding of insects and emulsification. Such "unclean" layers were readily detected, but the resulting thickness or volume measurement error could be corrected only through gravimetric analysis.

FIELD EVALUATION OF OIL SKIMMERS

The large weir-type skimmer described in the previous section, generally performed well in oil recovery operations on the Buffalo River, maintaining its high flow capacity and collection capability in the presence of all oil types and small debris. However, large debris did clog this unit, and it tended to tilt and become swamped in the presence of waves or during adjustment of the oil discharge hose. This instability caused excessive amounts of water to rush into the device resulting in markedly poor oil-to-water recovery ratios. It is believed that the addition of floats and stabilizers to this skimmer would overcome the instability problem.

The belt-type skimmer evaluated had disappointing performance throughout the program. It showed poor oil-to-water recovery ratios from the beginning, it was clogged with debris, thereby rendering it ineffective, and the congealed greases which were collected on the wiper blade would not flow spontaneously into collecting vessels.

The majority of field work during 1969 and 1970 was accomplished with the drum skimmer since it was used during the field program for a dual purpose, both to skim oil (as a surface cleansing tool) and as a sample collecting device (for the use of our analytical team assessing the actual nature of the oil present in each field location). This skimmer was either mounted along the shore in a stationary position or pushed ahead from a small boat at low speed. The rotating cylinder collected thicknesses of oil and water that depended only to a limited extent on the operating characteristics and to a major extent on the quality of the surface oil film actually present. In experiments conducted in the laboratory, where fresh oil was used, the pick-up thickness could be calibrated by making standard oil films of known thickness and measuring the volume collected per unit time per unit surface area. In principle, the rotating drum surface sampler makes possible rapid collection of samples of relatively undisturbed water and surface films for about the upper 100 microns of the water surface. However, in practice, this method has the problem of easy fouling by debris and greases. In addition, in the presence of weathered oil, as encountered in industrial watercourses such as the Buffalo River, the collected oil congeals into a very thick mass which will not even fall from a vertical surface. Analyses of samples collected with the rotating drum skimmer to determine oil-to-water recovery ratios showed that the material actually contained in the collection vessels was essentially clean water and that the skimmed oil fractions had accumulated (almost quantitatively) on the rotating drum wiper blade as congealed grease.

Because of the limitations of the various oil skimmers used in field operations on the Buffalo River, an entirely different system was selected for installation on the oil and debris recovery boat. Experience with the standard skimmer types showed that a light-weight unit capable of being easily lifted over containment booms and readily moved over the water as the surface oil becomes depleted is highly desirable. In addition, the overall oil-to-water recovery ratio should be high so that large volumes of water do not have to be stored onboard the boat.

After considering several alternatives, a suction-type system was selected in which the pump and other heavy components could be mounted on the deck. The system employs a light-weight pick-up hose having a simple skimming head which is easily maneuvered over the water surface by the operator. An on-board, oil-water separator removes up to 99 percent of the water skimmed at the surface. Because of the ease of maneuverability, the skimmer head can be moved to avoid interference by debris. The details of the oil and debris recovery boat are presented in a later section.

Use Of Piston Films As An Aid To Oil Skimming

It became evident early in the program that the efficiency of any type of skimmer, be it drum type, belt type, or weir type, could be markedly improved if some technique were available for concentrating the oil and directing it to a fixed location for retrieval by the skimming or collecting device. A recent development pioneered by a group at the Naval Research Laboratory, which has wide-spread potential application, is the use of surface chemical displacing agents as piston films for concentrating or controlling the oil slick size and motion. These compounds are non-toxic, surface-active chemicals that compete with the oil for space at the air/water interface. Thus, they very capably guide the oil away from the point of the chemical application and thicken the slicks of oil into more readily recoverable pools at locations chosen by the investigator and not by the meteorological nuances.

Light oils with some oxidized components should flow readily toward any skimmer as the oil burden at the skimmer is continually depleted. But this situation is rarely encountered on industrial waterways like the Buffalo River, or in a weathered oil spill at sea, because of the overriding effects of wind and current and the resistance of the more heavily weathered oils and emulsified surface sludges to spontaneous flow. Instead, it is more often observed that the skimmer efficiency drops to nearly zero within a few minutes after oil collection begins simply because there is no oil flowing into the immediate vicinity of the skimmer.

By the use of piston films, it was demonstrated during this program that the skimming operation at any location can be vastly improved. The piston films, spreading as monomolecular layers, compress, thicken, and drive the oily pollutants toward the operating skimmer from a large region. In one field test, for example, the following data were obtained with the belt-type skimmer mounted on a barge and used at the South Park Bridge Site, the most polluted site on the Buffalo River. For the first 10-minute operating period, the skimmer operated in a pool of heavily oil-coated water, collecting 460 cc within that 10-minute period, some 70 cc of which was oil. Over the next 10 minutes, with the immediate surface area nearly depleted of oil, the skimmer collected approximately the same liquid volume but only traces of oil were present in the material collected. In the final 10-minute evaluation period, drops of a piston-film forming agent (sorbitan monooleate) were applied around the periphery of the barge. The skimmer liquid sample collected in this period measured 480 cc with 40 cc of oil collected. Thus, a potential continuation of normal or near normal skimmer efficiency can be envisioned by the use of piston films to drive oil from inaccessible locations to the location of a fixed skimmer.

This concept naturally has its limits and will not by itself eliminate the need for portability of certain types of oil skimmers so that they can be relocated at will to strongly polluted areas or areas where oil spills have occurred. In particular, the piston films cannot overcome high currents or high winds. On the other hand, it is often possible to have the piston films deployed in the direction of the current and/or wind, in which case their effectiveness is even greater.

As a further demonstration of the field applicability of the piston film technique, we experimented with reels of special floating plastic rope which contained a coating of this surface-active agent as a persistent source. Reels were mounted in a tank in such a way that as the floatable rope unwound it passed through the piston-film-forming agent to achieve a uniform coating. In the field operations, the rope was unwound from the rear deck of the Buffalo Harbormaster's boat to encircle a large area of oil-covered surface where a sampling skimmer had been placed in the center. The rope itself acted as both the mechanical barrier and as an immediate source of the spreading agent. The rope material used was a multi-stranded, polypropylene filament which had many desirable features for this field testing. It provided a mechanical booming action because it did float at the air/water surface. It was twice as strong as manilla rope, resisted abrasion, was impervious to most of the industrial chemicals encountered over the field test program, and did not degrade from exposure to sunlight.

The same piston films tested on the river as aids in improving oil skimming operations were also instrumental in providing a quantitative technique for measuring the surface water quality (see section on sampling and analysis). Thus, we were able to compare empirically the effectiveness of various mechanical booms and skimmers in this Buffalo River project. Infrared "fingerprints" taken at identical locations before and after treatment with an oil-displacing compound demonstrated that even the grossest pollutant layers could be completely driven away from piers and shorelines and that the residual surface quality of even an industrial waterway can be greatly improved by application of the piston film method.

In ancillary experiments at Cornell Aeronautical Laboratory to assess the safety of the piston film agents to aquatic life and waterfowl, experiments were run with the culturing of brine shrimp beneath piston film-coated waters and with the provision of piston-film-coated waters as the exclusive drinking and swimming source for ducks. Also, large numbers and varieties of tropical fish in common aquaria were raised in waters covered continuously by excess quantities of the surface active agents. In not one of these instances was there any adverse effect of the presence of these compounds at the water surface.

SECTION IX
OIL SAMPLING, IDENTIFICATION, AND ANALYSIS

The sampling, identification, and analysis task on the Buffalo River Project had a two-fold purpose: (1) to develop reliable sampling techniques and identification methods for oily pollutants in an industrial watercourse which might be generally useful in similar watercourses across the nation, and (2) to develop a sufficiently detailed understanding and characterization of the Buffalo River oil pollution problem to allow effective control and abatement methods to be developed and to provide a measure of the effectiveness of eventual abatement and clean-up of the gross oil pollution noted there. This section of the report summarizes the tasks pertinent to sampling, identification, and analysis. For greater detail, the reader is referred to the topical report on this subject (Reference 2).

SAMPLING TECHNIQUES

Before a sampling program can be undertaken to characterize the extent of oil pollution, it is imperative that suitable oil sampling techniques be available that will provide a quantitative measure of the extent of the pollution, which in general persists on the surface, on the shoreline, in the bulk water, and in bottom deposits of the Buffalo River.

For collection of bulk water samples, a standard Kemmerer bottle having a 1200-ml capacity was used. Bottom sediment samples for oil analysis were gathered with a 6-inch Ekman dredge. For near surface samples, collection bottles were submerged with their mouths about a centimeter below the surface allowing the container to fill spontaneously. For outfall sampling, the mouth of the container was generally passed through the outfall stream from left to right at a point of its freefall to obtain a well-mixed representative cross-sectional sample. Since these methods are considered standard water sampling techniques, no further description is warranted here.

Measurement Of Shoreline Deposition

In order to determine quantitatively the amount of oil deposited on the shoreline, a series of test panels was constructed. The test panels consisted of plywood sheets to which were fastened ten aluminum strips coated with absorbent muslin cloth. Figure 27 shows a test panel in position at the South Park Bridge site. Each of the sampling panels was so placed that the individual sampling strips were approximately two-thirds submerged in river water. Each week over a 10-week period, one strip was removed from each panel, and the total oil content collected on the muslin cloth was determined by simple weighing. Over the course of the 10-week experiment, the muslin cloth deteriorated rapidly. Consequently, new muslin strips were installed from time to

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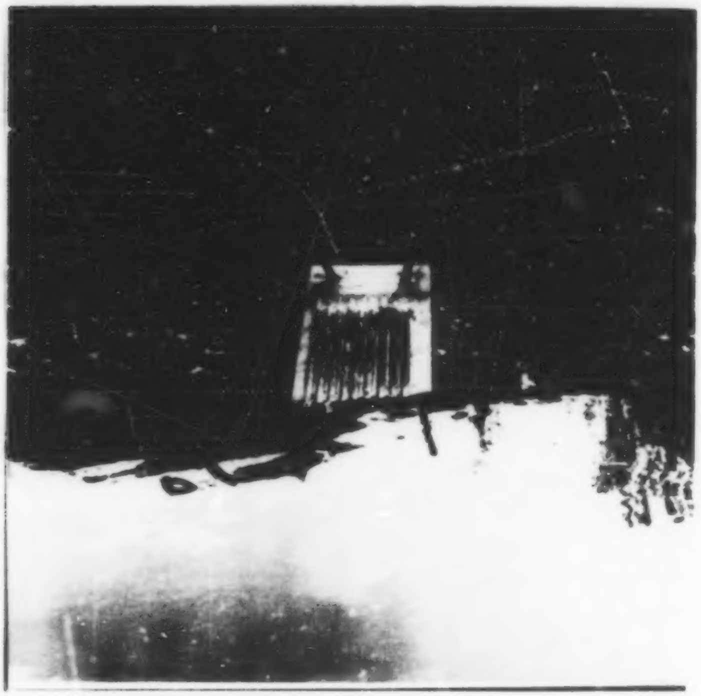


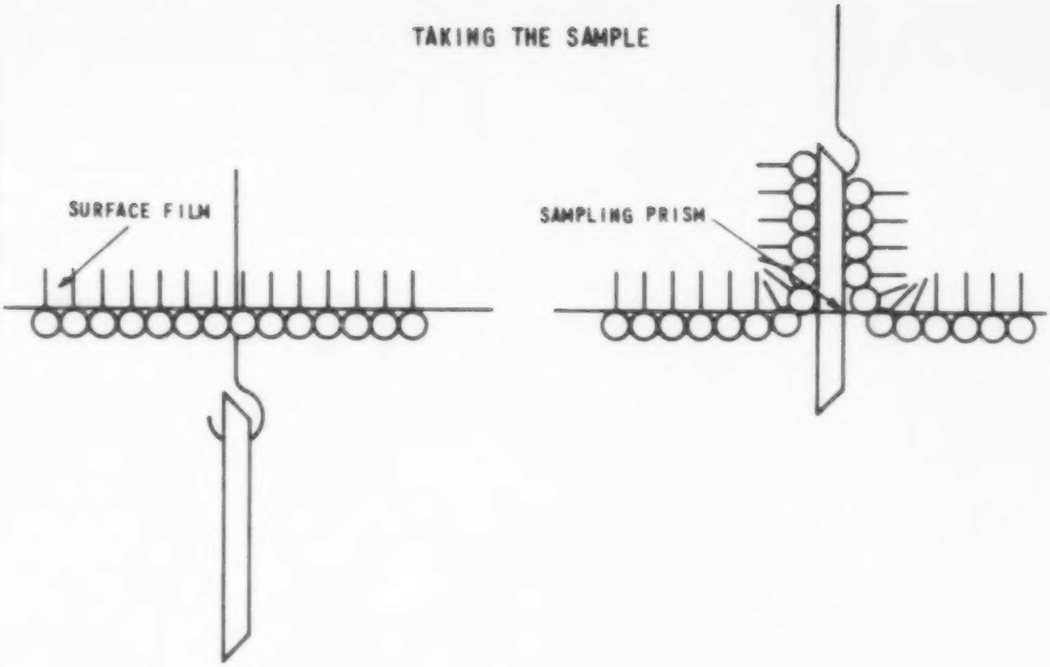
Figure 27 TEST PANEL IN POSITION AT SOUTH PARK BRIDGE SITE (SAMPLING SITE 5--FIGURE 2)

time and appropriate adjustments made in the oil accounting records. In a subsequent experiment to assess shoreline deposition, the goal was to simplify the field equipment sufficiently to suggest its general use in other industrial watercourses, and to chose sampling surfaces so designed that the minimum, rather than the maximum, amount of oil would be collected. In this effort, the sampling strips consisted of two 3-foot-long sections of 4-inch-wide aluminum flashing placed on top of one another and taped together along their outer edges with waterproof tape. The taping of the two strips facilitated their ready separation and allowed the recovery of the strips with oil deposits only on the outer surface facing the water. In this series of tests, no panels were used, and the strips were placed directly on the bank of the river. By separating the two sections of aluminum flashing after the strip was removed from the bank, any deposits of oil trapped under the strip or attached to it from pollutant loads already present when the strips were placed could be discarded.

For the collection of surface and near-surface samples, six different sampling techniques were evaluated. A brief description of each of these techniques is presented below:

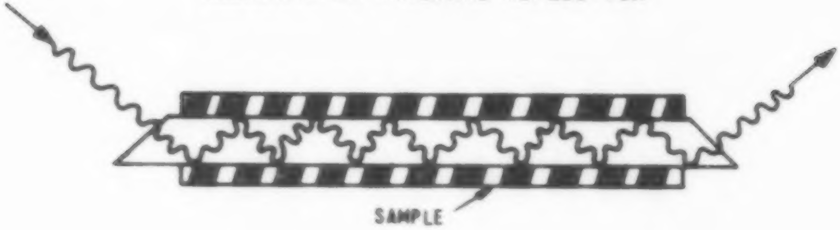
Prism Dip

In this technique, a simple prism having approximately the size and shape of a glass microscope slide is lowered through the contaminated water surface. The technique is illustrated in Figure 28. As the prism is raised out of the surface, the oil layer is transferred without significant thickness modification, no matter how thin the initial layer, to the sampling prism. Upon recovery, the sample is analyzed by internal reflection spectroscopy. As illustrated in the lower part of Figure 28, light enters the prism at one end and undergoes a large number of reflections at the prism-pollutant interface. The emergent light beam is then analyzed spectroscopically. When the prisms are analyzed by this technique, the strongest and most diagnostic infrared absorption band for hydrocarbons occurs in the frequency range from 2950 to 2850 cm^{-1}. The strength of this diagnostic absorption band increases with increasing oil thickness. Using an application of monomolecular layer technology, this increase in infrared absorption with increase in actual film thickness has been calibrated by producing films with thicknesses increasing in increments of approximately 50 Å. This calibration is valid to thicknesses on the order of 0.1 micron, since present prism materials have limited depths of penetration. This technique is simple to use and provides a rapid method for analyzing the characteristics of surface pollutants in actual watercourses. The sample analyses can be done on the spot using a portable infrared spectrometer.



TAKING THE SAMPLE

SURFACE FILM
SAMPLING PRISM



ANALYSIS BY INTERNAL REFLECTION

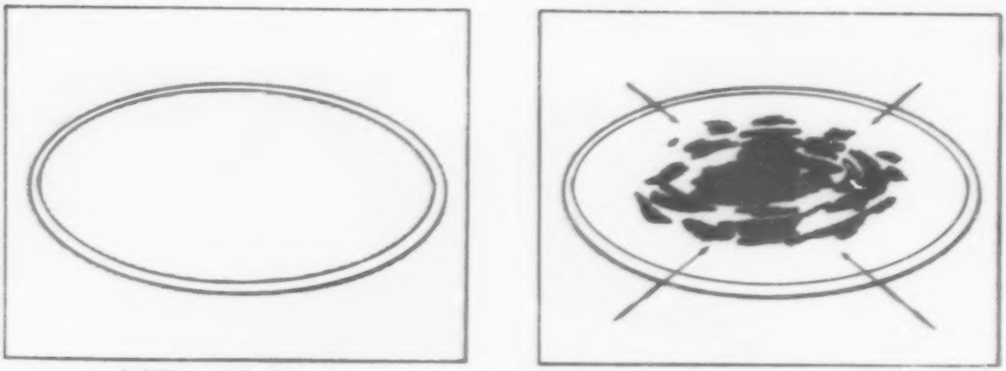
Figure 28 SCHEMATIC OF SURFACE FILM RECOVERY AND ANALYSIS BY INTERNAL REFLECTION METHOD

Surface-Active Hoop Techniques

This CAL-developed and field-proved sampling method for the collection of surface oils and other pollutant films is illustrated in Figure 29. This hoop sampling method confines, concentrates and quantitatively recovers surface oil films. In this method, a plastic hoop whose inside surface has been pre-wiped with a surface-active agent is deployed onto the water surface to be sampled. The surface-active agent spreads immediately from the inner surface of the hoop, thereby compressing the resident surface film of oil into a very small thickened area. Filter paper is then used to blot the concentrated film from the surface. By pre-weighing the filter paper, the sample that is recovered (per unit area) can be directly estimated simply by re-weighing the filter paper after drying. The amount of surface-active agent involved is so small that its weight is undetectable. This method has a deficiency in that very light oils, such as No. 2 fuel oil (in particular those freshly spilled), are not quantitatively collected because large portions of the sample can evaporate along with evaporation of the water during drying. However if immediate sample extraction by an organic solvent is substituted for drying, this objection is overcome.

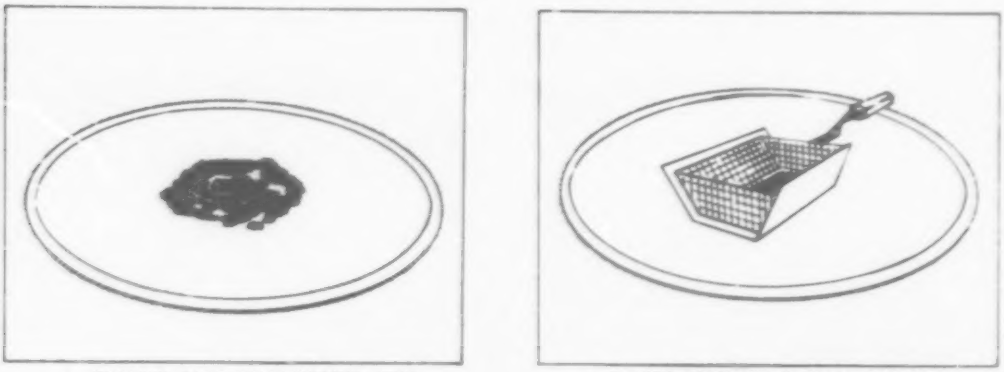
Screen-Sampling Method

The hoop method described above is very surface-specific. To determine the amount of oil present in the immediate subsurface waters, a screen sampling technique was selected which was introduced by a group at the Naval Research Laboratory some years ago. Figure 30 shows one simple screen device which embodies this concept and which is typical of the type used for sampling on the Buffalo River Program. To collect samples, the screen is simply touched to the water surface, lifted, and tilted so that the captured water is allowed to drain to one corner where it runs off into sample collection bottles. It has been estimated that the sample collected by this method represents only the top 0.04 cm of the surface water. Typical collections at a relatively clean location (Michigan Avenue Bridge site) showed water with a total oil and fat content of about 18 milligrams/liter, whereas the content from subsurface water (collected using a standard Kemmerer bottle) at depths from 7 to 21 feet averaged only about 4 milligrams per liter of the same organic pollutant. These results indicate that industrial watercourses can support considerably larger surface burdens of oily waste than is apparent from the films thinly spread over the water surface, and which are usually so thin as to show interference colors. The screen method of sampling is generally laborious and time-consuming. Similarly, useful subsurface samples can be obtained semi-automatically with the aid of a small rotating-drum unit described below.



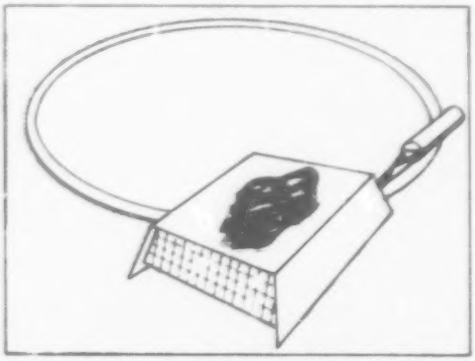
a. PLASTIC HOOP CONFINING KNOWN AREA OF SURFACE FILM

b. SURFACE FILM SPONTANEOUSLY COMPRESSED BY SURFACE-ACTIVE AGENT SPREADING FROM INNER PERIPHERY OF HOOP



c. SURFACE FILM CONCENTRATED INTO THICK POOL AT HOOP CENTER

d. FILTER PAPER ON SPECIAL FRAME IS TOUCHED TO OIL PATCH



e. OIL TRANSFERS COMPLETELY TO FILTER PAPER, AND IS READY FOR QUANTITATIVE ANALYSIS

Figure 29 TECHNIQUE FOR OIL FILM CONFINEMENT, CONCENTRATION AND QUANTITATIVE RECOVERY

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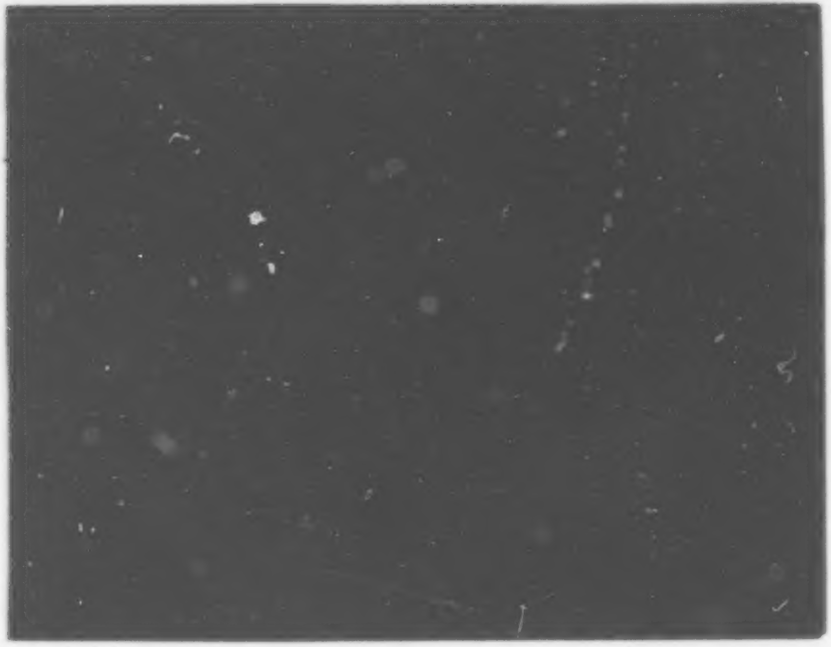

Figure 30 SAMPLING SCREEN USED TO COLLECT SURFACE POLLUTANTS

Rotating Skimmer Technique

A rotating drum skimmer based upon simplifications of a design originally presented by the Scripps Oceanographic Institute was constructed and tested for its utility as a sample collection device. Figure 31 shows a front view of the sampling skimmer. The samples are collected by the rotating drum whose surface is readily wetted by water.

A wiper blade pressed tightly to the surface of the drum removes both the water and any pollutant film as the drum rotates. The collected sample runs along the wiper blade into three separate containers. During field operations, the skimmer was either mounted along shore in a stationary position or pushed ahead from a small boat at a low speed. The skimmed surface water sample was estimated to represent only the upper most fraction of an inch of the water, as in the case of the screen sampling method. For the sampling skimmer shown in Figure 31, the cylinder was 15 inches in diameter and 24 inches in length. At a reasonable rotation rate, an area of about 1,000 square meters could be sampled in an hour making the technique more than competitive with the sample screen technique. The method, however, has the same problem encountered with the metal screens in the screen-dip technique discussed above; namely, easy fouling by debris and greases. It does, however, allow a collection of a surface sample with a minimum of vertical mixing.

Figure 31 SAMPLING SKIMMER – FRONT VIEW

Funnel Dip Technique

The funnel dip technique for surface sampling was discussed in the previous section on oil skimming. This technique is illustrated in Figure 32. The sampling funnel is generally cleaned in a hot soap solution, and after a quick towel drying of its outside surface, is slowly dipped, large end first, into the water. Any surface oil present is driven toward the center of the funnel and as the funnel is continually lowered the oil collects in the stem. When the stem end of the funnel is sealed by finger pressure, the oil column will remain in the stem end after the funnel is lifted out, even though in most instances it was observed that the bulk of the liquid in the wide end of the funnel is immediately lost. The length of the oil column collected in the stem multiplied by the ratio of the stem area to the funnel area provides a rapid estimate of the actual film thickness present. This method does not work well for weathered oils, debris laden films, or emulsified surface layers.

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Figure 32 FUNNEL DIP TECHNIQUE

In-Situ Freezing Technique

The techniques described above were found to be completely inadequate for thick emulsified and debris laden layers of oil found in the Buffalo River at certain natural concentration points or collected along booms. Thus, a technique was required for retrieving representative samples from defined surface areas for oil thicknesses sometimes in excess of 3 inches along various lengths of the shoreline. Figure 33 illustrates simple, inexpensive equipment developed at CAL as a solution to this sampling problem. This equipment extended the capability for quantitative recovery of oil films a few centimeters thick to films many inches thick and beyond, even though these slicks are very heterogeneous in character and contain debris of large and irregular sizes. Stiff aluminum frames, open at the top and bottom, were fabricated. These forms contain a known slick surface area as they are placed on the polluted oil surface. The aluminum form, which was found in normal operation to sink to the full depth allowed by its design, occasionally had to be forced through the debris laden grease accumulations. Once the form was in place, the contained oily mass was immediately solidified by pouring liquid nitrogen into the upper opening of the form. It was found that simple thermos bottles filled with liquid nitrogen the morning of the sampling day were adequate to handle most sampling needs over an 8-hour period. When the liquid nitrogen was poured from the thermos container into the upper opening of the form, the aluminum frame was such a good thermal conductor that the oil mass was quickly frozen to the form periphery. Very little water below the pollutant slick was trapped frozen to the solidified oil and debris. The frozen samples were lifted from the water surface with tongs and placed in storage containers for later weighing and analysis in the laboratory.

SUMMARY OF SAMPLING TECHNIQUES

A qualitative comparison of the sampling techniques used in the Buffalo River Project is given in Table 3. In this table, each sampling method used, with the exception of that used for shoreline oil deposition measurements, is listed along with its most frequent application. Significant advantages and disadvantages noted in the field are also specified.

SAMPLING PROGRAM

A brief sampling series was conducted in the late fall of 1968 on the Buffalo River before the winter freeze set in. A major sampling and identification program was begun in June of 1969. Since the early program emphasis was placed on booms, skimmers, and air barrier evaluation, very little actual analysis of the bulk river water and of the distribution of the pollutant oils was attempted. The bulk water sample analysis over the summer of 1969 was based on a single solvent extraction technique which more careful work in the subsequent year demonstrated to be inadequate. In 1970, a regular sample collection program began in April and terminated in October providing an

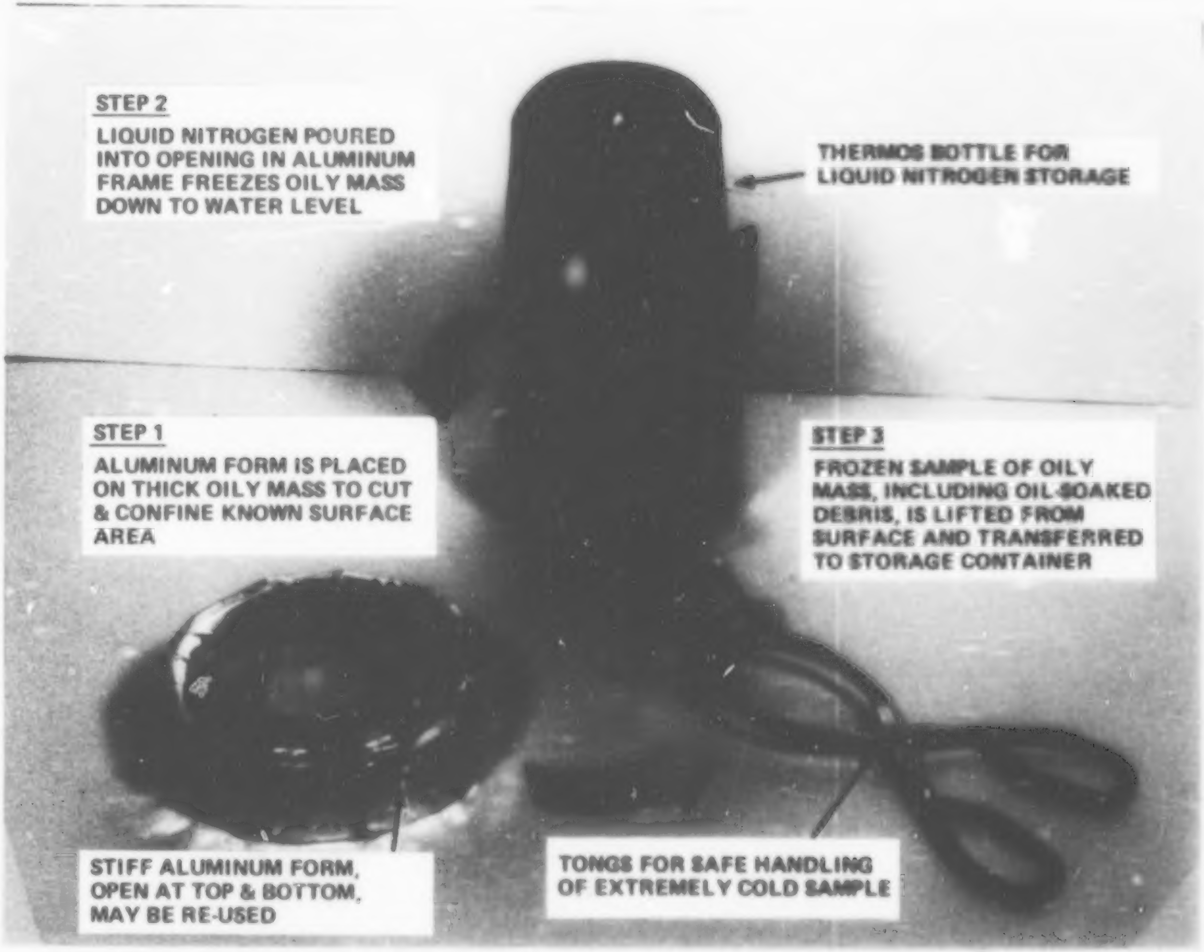
STEP 2
LIQUID NITROGEN POURED INTO OPENING IN ALUMINUM FRAME FREEZES OILY MASS DOWN TO WATER LEVEL
THERMOS BOTTLE FOR LIQUID NITROGEN STORAGE
STEP 1
ALUMINUM FORM IS PLACED ON THICK OILY MASS TO CUT & CONFINE KNOWN SURFACE AREA
STEP 3
FROZEN SAMPLE OF OILY MASS, INCLUDING OIL-SOAKED DEBRIS, IS LIFTED FROM SURFACE AND TRANSFERRED TO STORAGE CONTAINER
STIFF ALUMINUM FORM, OPEN AT TOP & BOTTOM, MAY BE RE-USED
TONGS FOR SAFE HANDLING OF EXTREMELY COLD SAMPLE

Figure 33 SIMPLE EQUIPMENT FOR QUANTITATIVE RECOVERY OF THICK OIL ACCUMULATIONS

Table 3

COMPARISON OF SAMPLING TECHNIQUES USED

SAMPLING METHOD	MOST FREQUENT APPLICATION	ADVANTAGES NOTED	DISADVANTAGES NOTED
PRISM DIP	THIN NATURAL AND POLLUTANT FILMS (0 TO 1 μm) INDUSTRIAL OUTFALLS SEWER LINES	RAPID POTENTIALLY CHEAP AND DISPOSABLE UNIVERSAL ALLOWED INFRARED IDENTIFICATION OF MATERIALS AS WELL AS QUANTITATIVE AMOUNT FOR THINNEST FILMS	NOT QUANTITATIVE FOR MODERATELY THICK FILMS ONLY A QUALITATIVE INDICATOR FOR THE CHEMISTRY OF VERY THICK FILMS
SURFACE ACTIVE HOOP	MODERATELY THICK POLLUTANT FILMS (0.1 μm TO 1 cm) ALTHOUGH GOOD FOR THINNER FILMS AS WELL	QUANTITATIVE SAMPLE RECOVERY BROAD RANGE OF FILM THICKNESSES REASONABLY LARGE SAMPLE RECOVERY POSSIBILITY OF GOOD STATISTICS FROM NUMEROUS SAMPLES	DEPLOYMENT IN HIGH WINDS OR HIGH CURRENT DIFFICULT
SCREEN DIP	SURFACE WATERS "CLEAN" OR OIL COATED	LARGE SAMPLE RECOVERY SIMPLE APPLICATION	LABORIOUS TO USE EASILY FOULED BY WEATHERED OIL AND DEBRIS
FUNNEL DIP	MODERATELY THICK POLLUTANT FILMS (0.1 μm TO 1 cm) BUT SELDOM USED IN FIELD BECAUSE SAMPLE QUANTITY TOO SMALL	RAPID IMMEDIATE ESTIMATE OF FILM THICKNESS	NOT APPLICABLE TO EMULSIFIED OIL OR DEBRIS LADEN OIL VERY LITTLE SAMPLE RECOVERED FOR ANALYSIS RANGE OF FUNNEL SIZES REQUIRED FOR BROAD UTILITY
ROTATING SKIMMER	SURFACE WATERS "CLEAN" OR OIL COATED	LARGE SAMPLE RECOVERY AUTOMATIC OPERATION OVER LONG PERIODS OF TIME POTENTIALLY MOBILE	EASILY FOULED BY DEBRIS AND THICK FILMS REQUIRES EXTERNAL POWER (BATTERY)
IN SITU FREEZING	THICK POLLUTANT FILMS "CHOCOLATE MOUSSE" DEBRIS LADEN FILMS MANY CENTIMETERS THICK	QUANTITATIVE RECOVERY EXTREMELY THICK AND DEBRIS LADEN SAMPLES EASY FIELD DEPLOYMENT LARGE SAMPLE RECOVERY	LACK OF AVAILABILITY OF FREEZING CHEMICAL AT SOME FIELD SITES
KEMMERER BOTTLE	SUBSURFACE WATERS AT VARIOUS DEPTHS	EASY ROUTINE DEPLOYMENT	SUBJECT TO ERRATIC OPENING AND DISCHARGE OF SAMPLE AT TIMES
BAG SAMPLES	IMMEDIATE SUBSURFACE WATERS (1 cm DEPTH) AND INDUSTRIAL OUTFALLS	SIMPLE ROUTINE DEPLOYMENT BAGS STORE FLAT WHEN EMPTY AND ARE LIGHTWEIGHT	LIMITED TO OUTFALLS OR SURFACE WATERS OCCASIONAL PROBLEMS WITH LEAKS
EKMAN DREDGE	BOTTOM SEDIMENTS	ROUTINE RELIABLE METHOD ADEQUATE SAMPLE SIZE	SUBJECT TO ERRATIC OPENING AND DISCHARGE OF CONTENTS AT TIMES

extensive series of measurements upon which the major conclusions of the sample analysis phase of the program are based. Twelve specific sampling sites were selected as shown in Figure 34. Surface samples, bulk water samples, and near-bottom samples were taken at each of these 12 sites on a weekly basis throughout the sampling period. In addition to these specific 12 sites shown in Figure 34, samples were also collected at other sites when unusual conditions were observed. Samples were also collected from industrial outfalls along the length of the Buffalo River.

For evaluation of the deposition of oil on the shoreline, tests using the muslin-coated strips were conducted over a 10-week period in 1969. Each week of the 10-week period, one of the muslin coated strips was removed at each of the sites for analysis. In 1970, a 5-week sampling program for evaluating shoreline deposition was undertaken.

Sample Analysis And Identification

Samples collected during the 1969 and 1970 sampling programs on the Buffalo River were analyzed for each of the following parameters where appropriate:

1. pH
2. Solvent extractable material
3. Dissolved solids
4. Ultra-violet/visible spectra
5. Infrared spectra of residues from the samples themselves and of their solvent extractable material
6. Gas chromatograms

In special instances, the following measurements were also made:

1. Atomic absorption spectra (for trace metals)
2. Surface tension (obtained to address questions of potential emulsification)

In addition, dissolved oxygen and temperature were measured in the field during the 1970 sampling program. Early in the program, a standard ASTM method based upon hexane extraction of industrial waste waters followed by column adsorption techniques, had been considered to be the most likely to succeed on a basis of experience related to us informally by other groups. As the program proceeded during late 1968 and early 1969, evidence accumulated from other phases of the program which indicated that many of the major oily pollutants known to be present were either not detected or not differentiated by this standard method. Problems that were found included insolubility of some of the components in hexane, and also inadequacy of material separation by

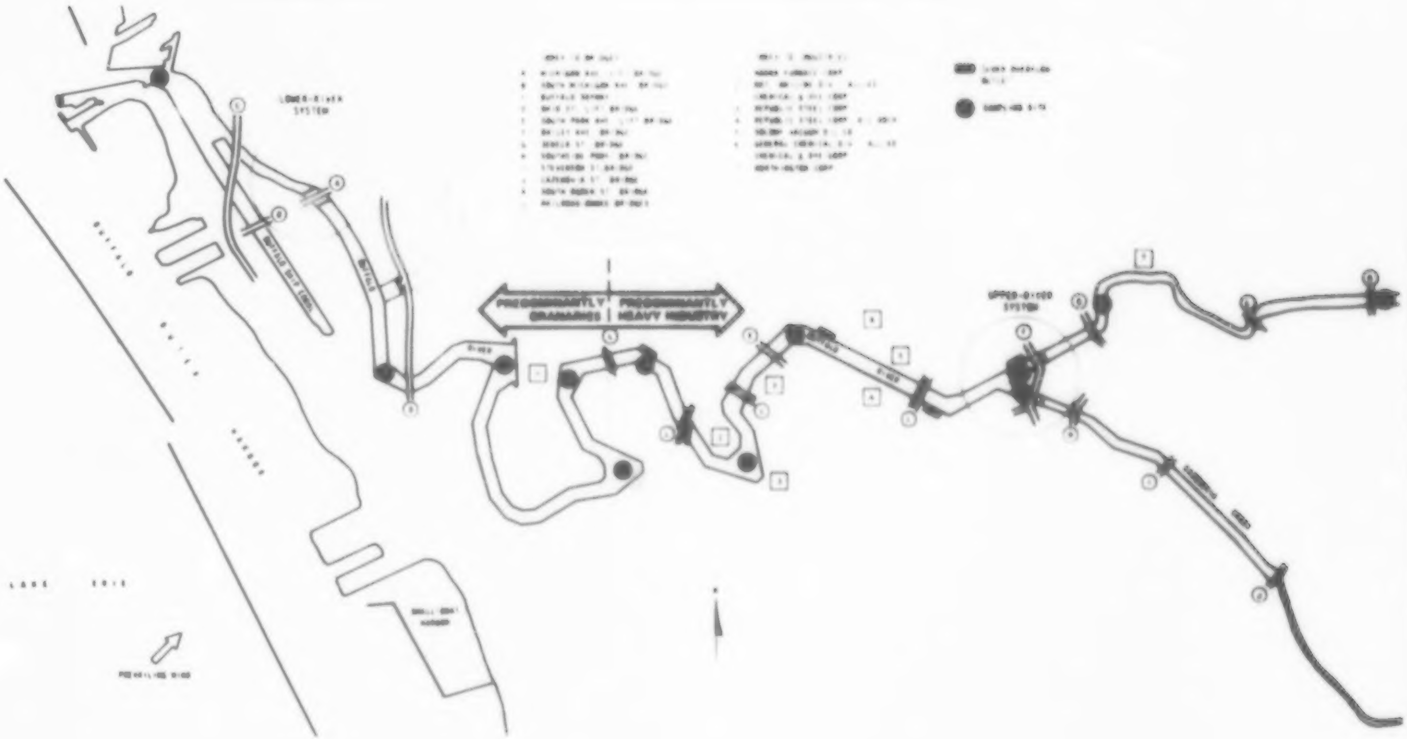
LOWER-RIVER SYSTEM
UPPER-RIVER SYSTEM
PREDOMINANTLY GRANARIES
PREDOMINANTLY HEAVY INDUSTRY

Figure 34 CHOICE OF SITES FOR BUFFALO RIVER SAMPLING PROGRAM

column filtration. Therefore, a major task early in the analytical program was the development of a reliable combined chemical-instrumental method that could provide the desired data on the quality and quantity of the dissolved or suspended pollutants in waters of an industrial stream. Of the many approaches considered, the combination of solvent extraction followed by infrared spectroscopy of the extracts showed the greatest promise and was, therefore, developed further and became the routine method.

The specific infrared technique which was found to be of the greatest utility in the course of the program was that of internal reflection spectroscopy. This technique was illustrated earlier in the lower portion of Figure 28. For sample collection, the prism is dipped directly into the watercourse. When used in connection with the solvent extraction technique, the solvent extract is simply evaporated to dryness on the prism plate, and the prism is then subjected to spectroscopic analysis.

In the course of seeking a substitute for the hexane extraction technique for hydrocarbons and oily pollutants in industrial waterways, a number of organic solvents were considered, the best of which and the most reliable of which was found to be chloroform. Tests clearly illustrated the superiority of the chloroform extraction technique over the hexane extraction technique for both the qualitative and quantitative indication of hydrocarbon pollutants in water samples collected from the Buffalo River. The chloroform extraction method used in this program is described in detail in Appendix B of Reference 2.

While the use of chloroform as a solvent proved to be most useful, there were exceptions. For the industrial outfall samples collected, the extraction solvent was selected on the basis of the recorded pH values. For pH values on the basic side, it was found that chloroform was an unsuitable solvent. For outfall samples having a pH value greater than 8, carbon tetrachloride was used as the solvent.

For complete descriptions for the analytical methods used in this program, the reader is referred to Reference 2.

For identification purposes, infrared spectroscopy based upon the internal reflection technique discussed earlier, ultra-violet spectroscopy, and gas chromatography were found to be particularly good methods. Figure 35 is a composite infrared spectrum of all the pollutants that were considered to be discharged regularly into the Buffalo River from the major industries. This artificial spectrum was created by superimposing the typical traces from each of the major industrial sources. The major infrared absorption band centered at 2900 cm^{-1} noted in this spectrum is associated with the presence of oils or oil-based organic pollutants, as are the two less intense bands which bracket the 1400 cm^{-1} frequency line. The rest of the complexity in the composite spectrum in Figure 35 can be attributed almost completely to the presence of a large variety of dyes present in the effluent from one of the major

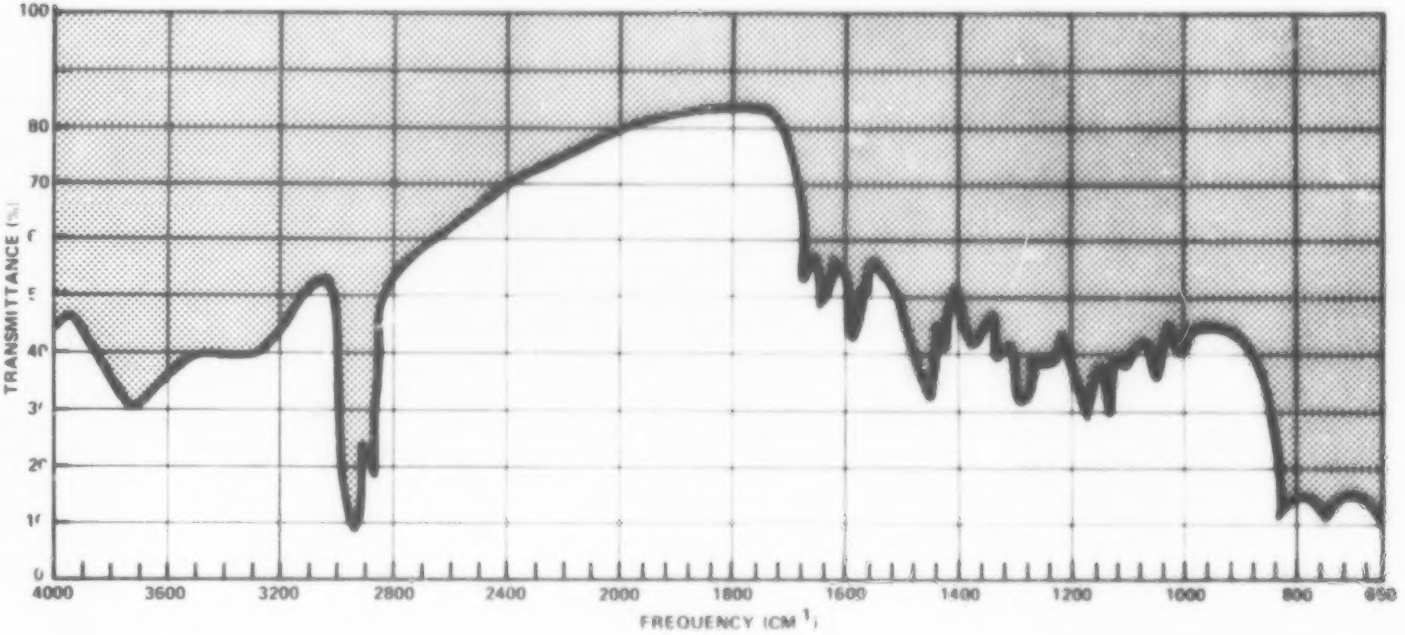

Figure 35 COMPOSITE INFRARED SPECTRUM OF MAJOR BUFFALO RIVER POLLUTANTS DERIVED FROM INDUSTRIAL OUTFALLS

industries. The spectrum also includes absorption bands characterizing some proteinaceous effluents from the various sewer overflows and from the granaries along the lower half of the river. Individual spectra derived from samples collected from the various industries on the Buffalo River are presented in Figures 67 and 68 of Reference 2. These spectra are the basis for the composite spectrum shown in Figure 35. If the obvious surface pollution of the Buffalo River is predominantly of industrial origin no spectrum characterizing a "natural" midstream pollutant slick should be substantially more complex than the artificial summation spectrum given in Figure 35. Neither should such a spectrum include absorption peaks not present in Figure 35. Actually, spectra simpler than the composite are almost more certain to be found because of the lack of opportunity for thorough mixing of the various pollutants on the river surface from the geographically separated sites along the river. During the course of the program, it was found that infrared spectra of samples collected along the surface of the Buffalo River had characteristic peaks which coincided with absorption peaks in the composite spectrum shown in Figure 35. Cross comparison of the infrared spectra taken from the industrial outfalls and samples taken midstream on the Buffalo River illustrated that the midstream pollutant samples were often readily associated with nearby industrial outfalls giving rise to them. For example, the spectra of a surface film in the industrial segment of the river often contained infrared bands that could only be correlated with the color dyes in the effluents from one of the chemical companies.

A study of the ultra-violet spectra of the various industrial outfalls also revealed certain details useful for classifying the pollutants. Spectra of sixteen industrial outfalls were amenable to fitting to only four basic ultra-violet spectra (spectra recorded over the 200 to 350 nanometer range). The details of the ultra-violet correlation studies are presented on page 139 of Reference 2.

Gas chromatography proved to be an effective tool for analysis of samples taken in connection with the evaluation of the trapping efficiencies of an inverted siphon located on Memorial Drive in the City of Buffalo. Gas chromatograms made it possible to distinguish between biological components entering the inverted siphon and No. 2 fuel oil which entered from a nearby railroad refueling terminal.

Results Of Sampling Program

Major results from the sampling program carried out on this project are shown in Figures 36, 37 and 38. The indicated oil concentrations are based on the chloroform extraction technique discussed previously. The sampling sites are numbered in accordance with Figure 34. In each of the three figures, selected sampling dates are shown. Also shown are averages of all data points taken over all data collection dates throughout the entire sampling program for 1970. Figure 36 illustrates the much higher surface burden of oils found in the vicinity of heavy industry along the river as contrasted to both the upstream

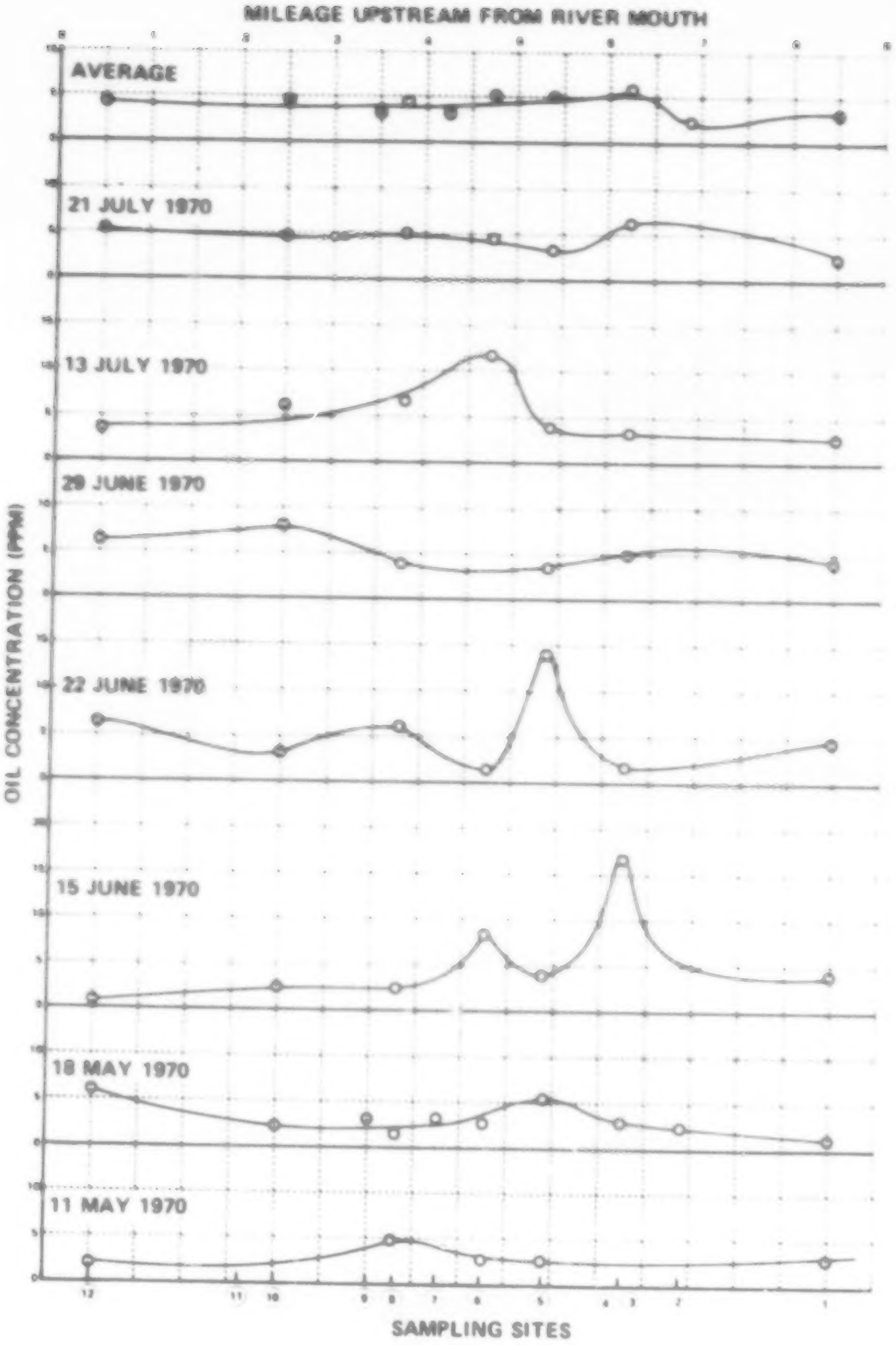

Figure 36 PROFILES OF BUFFALO RIVER SURFACE-WATER BURDEN OF CHLOROFORM-EXTRACTABLE OILY POLLUTANTS

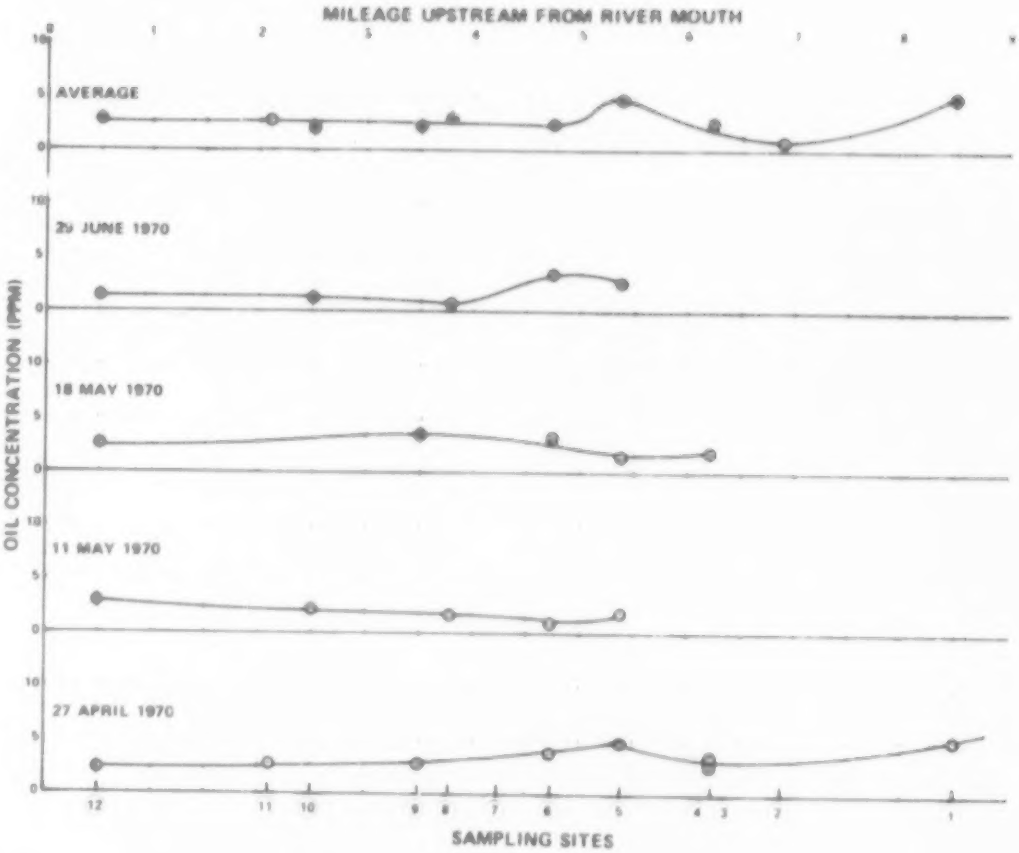

Figure 37 PROFILES OF BUFFALO RIVER BULK-WATER BURDEN OF CHLOROFORM-EXTRACTABLE OILY POLLUTANTS

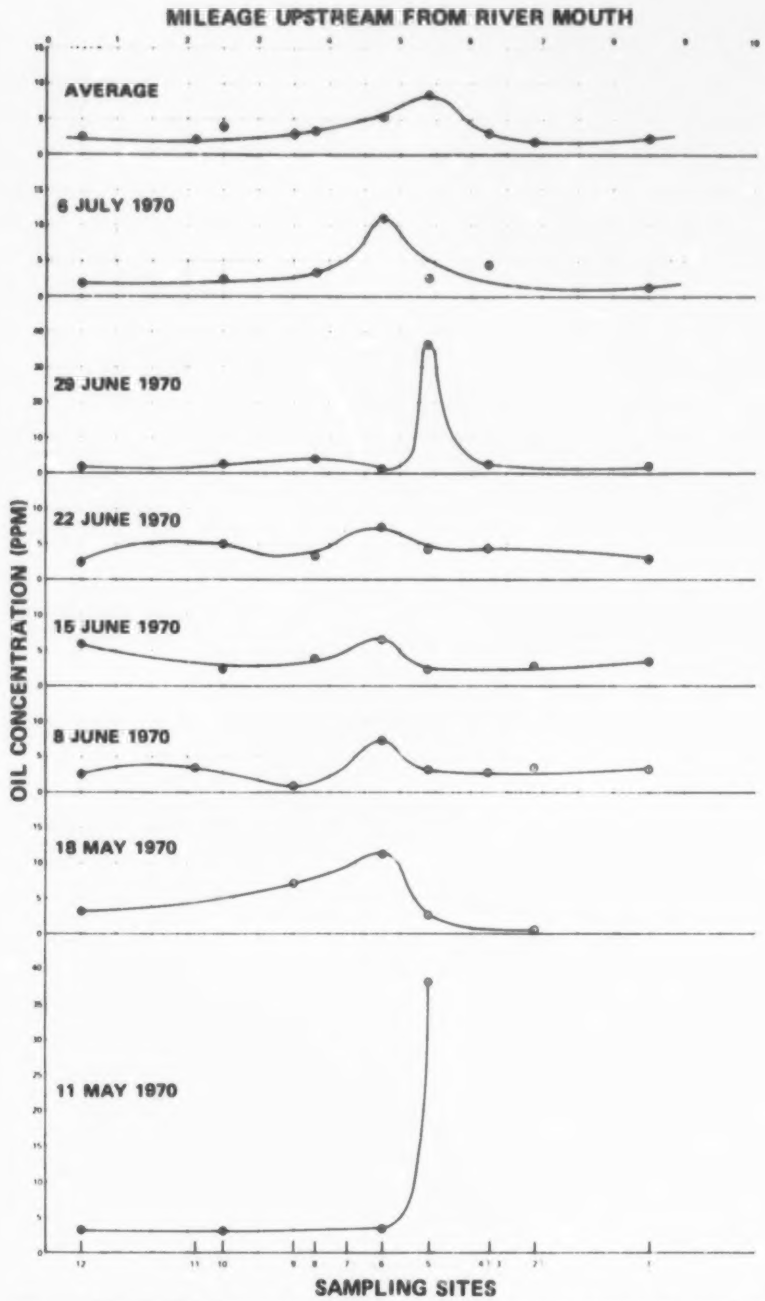

Figure 38 PROFILES OF BUFFALO RIVER BOTTOM-WATER BURDEN OF CHLOROFORM-EXTRACTABLE OILY POLLUTANTS

and downstream portions. Figure 37 includes profiles of the Buffalo River at the 3-meter depth and illustrates a similar variance in concentration but to a much lesser degree. On the other hand, Figure 38 shows a dramatic increase in oily pollutants in the bottom waters of the river in the most highly industrialized section.

Having isolated the heaviest concentration of oily pollutants in the Buffalo River to this reasonably short 2-mile segment, an additional amount of sampling and analytical work was warranted to attempt a correlation of oil concentrations with depth in this segment. Figures 39 and 40 present vertical profiles of the chloroform-extractable matter at sites 5 and 6 in the Buffalo River. These figures demonstrate both the very high concentration of oily pollutants near the surface and near the bottom at each of these sites, and a much lower concentration in the bulk water flow between the first foot of the water surface and the last foot near the bottom. The prevailing up-river winds couple to the surface pollutant layers and keep them "bottled up" in the upstream portion. The increase in concentration of pollutants near the bottom is attributed to sedimentation of the pollutants on solids from industrial outfalls and general trapping of oils in the sediment. Under a Buffalo River Improvement Project, water is pumped from Lake Erie through various industries on the river into the Buffalo River. In this pumping program it has been stipulated that the flow in the river must be maintained at 100 million gallons of water per day. This tends to account for the somewhat lesser pollution burden in the bulk waters of the river, and in fact, observations of data collected in previous years have shown that the bottom sediments are noticeably "cleaner" since initiation of the Buffalo River Improvement Project.

Using the data contained in Figures 36 through 40, the vertical distribution of oil in the river was calculated. Considering a vertical column in the industrial sector, having a 1-foot-square cross section, it was found that 44×10^{-8} lb of oil could be present on the surface and that 49×10^{-4} lb of oil was present in the bulk water column extending from just below the surface all the way to the bottom of the river. Thus, 10,000 times more oil is contained in the bulk water than on the surface of the river. It is not known to what extent emulsifiers may have been deliberately added to the oil discharges. Assuming a mean daily water flow of 325 cubic feet/second, the oil in the bulk water corresponds to 5300 lb/day of oil being carried in the river in the industrial sector.

The studies of shoreline deposition of oils carried out in 1969 and 1970 showed that oil deposition in the upper river segment was about one hundred times greater than at the Michigan Avenue Bridge site. The study also showed that in any sampling interval a net loss of oil can be observed from the test strips, and hence from the shoreline itself presumably. In general, the muslin coated strips collected much greater quantities of oil than did the plain aluminum strips as was anticipated. Data from the muslin coated strips suggest that 100 to 500 gallons of oil per day could be deposited on the shore in the 2-mile length of the industrial area.

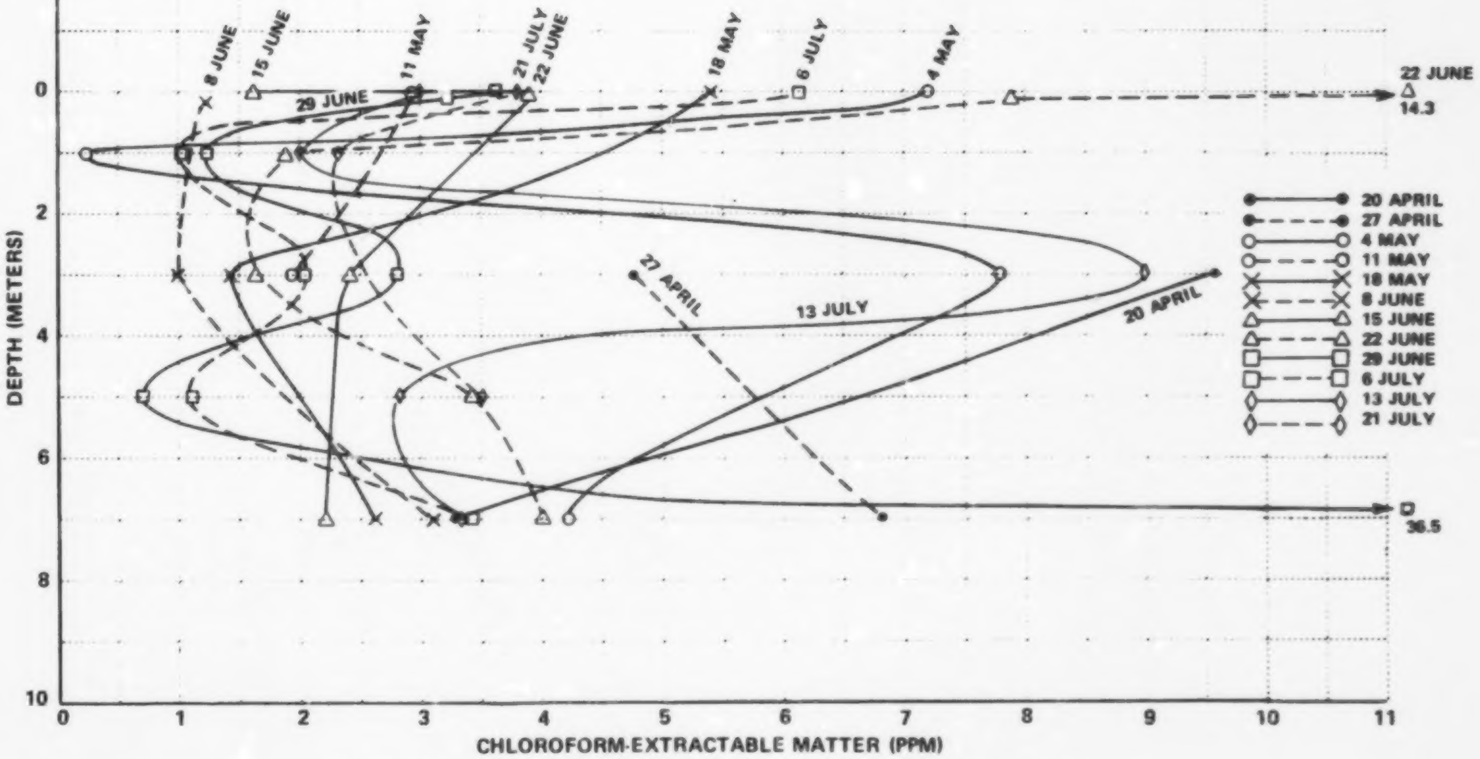

Figure 39 VERTICAL PROFILES OF CHLOROFORM EXTRACTABLES FOR SAMPLING SITE 5 (1970)

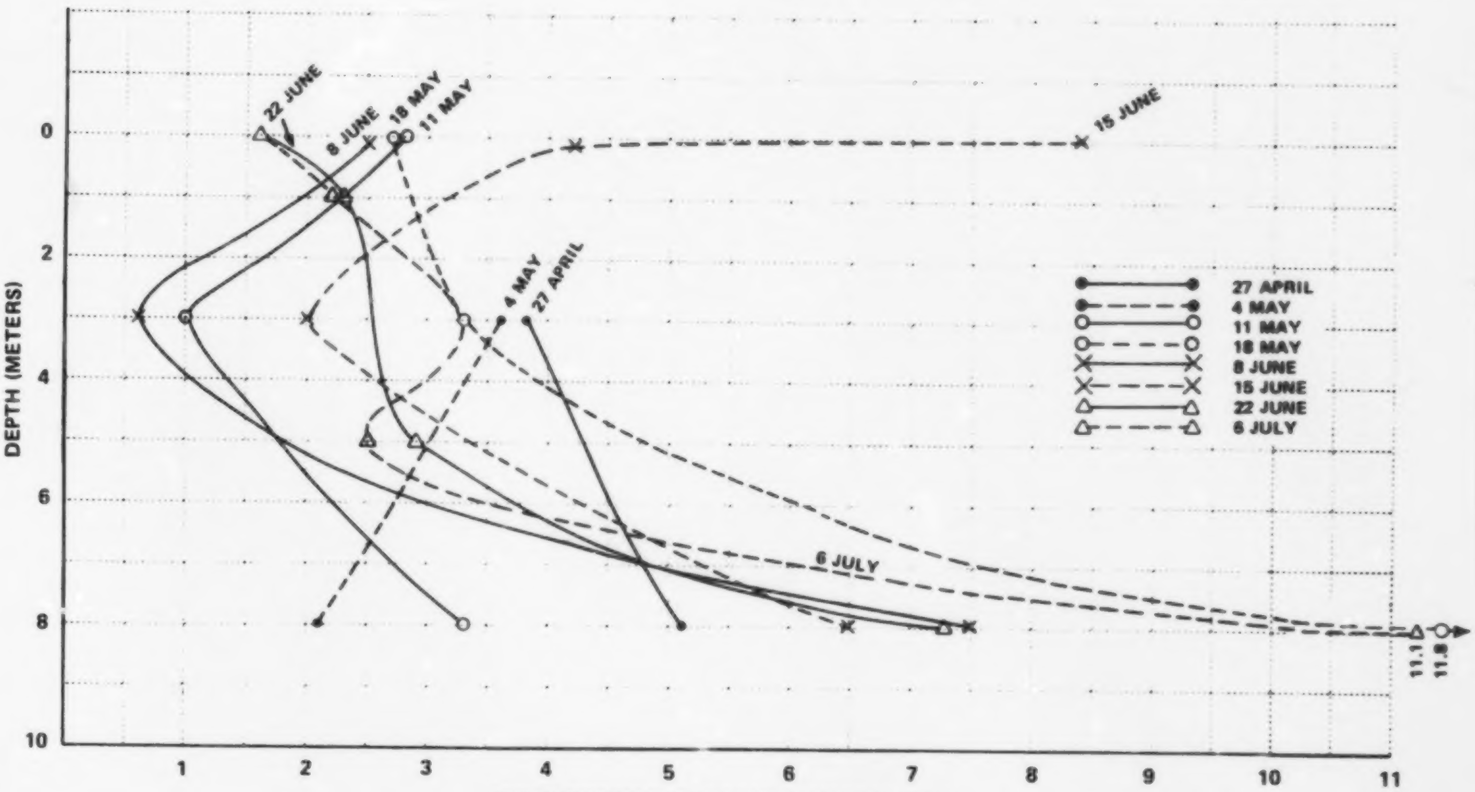

Figure 40 VERTICAL PROFILES OF CHLOROFORM EXTRACTABLES FOR SAMPLING SITE 6 (1970)

SECTION X

IN-SEWER INSTRUMENTATION

The largest fraction of oil pollution in the Buffalo River can be attributed to industrial sources located on the river. However, since the objective of the present program was to develop methods of preventing and eliminating pollution of the Buffalo River, all possible sources of discharge had to be considered. In cities in which sanitary and storm sewers are combined, oil in the sewer system can be discharged into the watercourses during times of heavy storm when overflow chambers allow both sanitary and storm water to discharge directly into local watercourses to prevent overload of the sanitary sewage treatment facility. In Buffalo, a number of the storm overflows enter into the Buffalo River, and, hence, are a potential source of pollution. In general, it is extremely difficult to enforce sewer regulations against the discharge of oil since the potential points of discharge are so numerous and often the problem is not detected until oil reaches the treatment plant. Therefore, the present project included the development of instruments suitable for installation in the sewer environment that could detect oil automatically and, via a telemeter system, provide an indication of violations directly to a central facility. A reasonable number of oil monitors in each city appear to be adequate for this purpose. For example, in the City of Buffalo it has been estimated that some sixty sensors, strategically placed, could locate most major sources of oil.

THICK FILM OIL DETECTORS

Prior to the initiation of the Buffalo River Program, it had been observed that large oil accumulations occur in the inner manholes of inverted siphons. (See the following section for discussion of trapping in inverted siphons). Oil accumulations in these manholes often reach several feet. Therefore, it was desirable to develop an oil detector capable of sensing oil layers in excess of several centimeters up to several feet. A number of different sensor designs were considered for detecting thick oil layers. Two of the more promising ones were an RF conductivity sensor and a thermistor sensor. The RF conductivity probe designed for use in the present program consisted of a coil wound with stainless-steel wire and energized with an alternating current, at a frequency of about 10 megahertz. When the coil is surrounded by a conductive fluid, part of the generated power is absorbed by the fluid. The amount of power absorbed, which is measurable, depends on the conductivity of the fluid. This device easily indicated the conductivity of water for dissolved ion solute concentration of some 5 parts/million and higher. Concentrations lower than 5 ppm are almost never found in water that has not recently been distilled. Thus, the device can easily distinguish between oil and water in sewers. Oils which accumulated in the manholes in the inverted siphon were easily detected by this RF oscillator probe.

The thermal conductivity probe employs a self-heated thermistor, whose resistance indicates its temperature, to distinguish sewer fluids in which it is immersed on the basis of the heat exchange characteristics. Basically, the unit contains one thermistor, one small incandescent light bulb, a rheostat, an indicating meter, and a battery. The thermal probe easily distinguishes between normal sewage and oil.

For measurements in the inverted siphon, two sensors (one of the electrical conductivity type, and the other of the thermal conductivity type) were incorporated into a single battery-operated portable probe as shown in Figure 41. The stainless-steel wire coil for the electricl conductivity sensor is at the left in the figure. The right end of the probe contains a self-heated thermistor within the hollow tube. The case shown contains meters, circuitry, and batteries. The electrical cable is marked at 1-foot intervals to permit the depth of the sensor from the top of the manhole to be determined. This ruggedized probe was evaluated by personnel of the Buffalo Sewer Authority and Cornell Aeronautical Laboratory and found to be a convenient and effective means for determining the level and thickness of oil collected in the manholes of the inverted siphon. In fact, the probe has been used by the Buffalo Sewer Authority to collect oil-accumulation data.

To evaluate the suitability of the electrical conductivity sensor and the thermal conductivity sensor to withstand the sewer environment on a long-term basis, an experimental instrumentation probe was built and installed in the inverted siphon. This probe consisted of a total of 13 sensors, six of the electrical conductivity type and seven of the thermal type, spaced alternately at 1-foot intervals along the length of 18 feet of polyvinyl chloride tubing. The tubing was positioned so the upper-most sensor was approximately 6 inches above the usual level of sewage in the manhole. The bottom sensor was approximately flush with the bottom of the manhole sheath extending into the siphon as shown in Figure 42. Oil depth measurements were made by removing the manhole cover and attaching the probe cable to a portable readout device. Following the initial evaluation of the fixed instrumentation probe, a more permanent installation was fabricated which permitted the oil depth measurement to be made automatically at selected intervals and telemetered from the site to a receiver and recording station located at Cornell Aeronautical Laboratory, a distance of several miles away. The new probe consisted of eight radio-frequency electrical conductivity probes spaced at 1-foot intervals along a 34-millimeter diameter polyvinyl chloride pipe, 10 feet in length. The upper end of the pipe was attached to a polyurethane foam float enclosed in an aluminum housing for impact protection. The completed probe is shown in Figure 43 before installation in the siphon. The flotation device allows the entire probe to be floated vertically in the manhole. Oil depths up to 8 feet could be measured with this unit. A complete description of this unit along with circuit diagrams is given in Reference 3.

Figure 41 PORTABLE PROBE

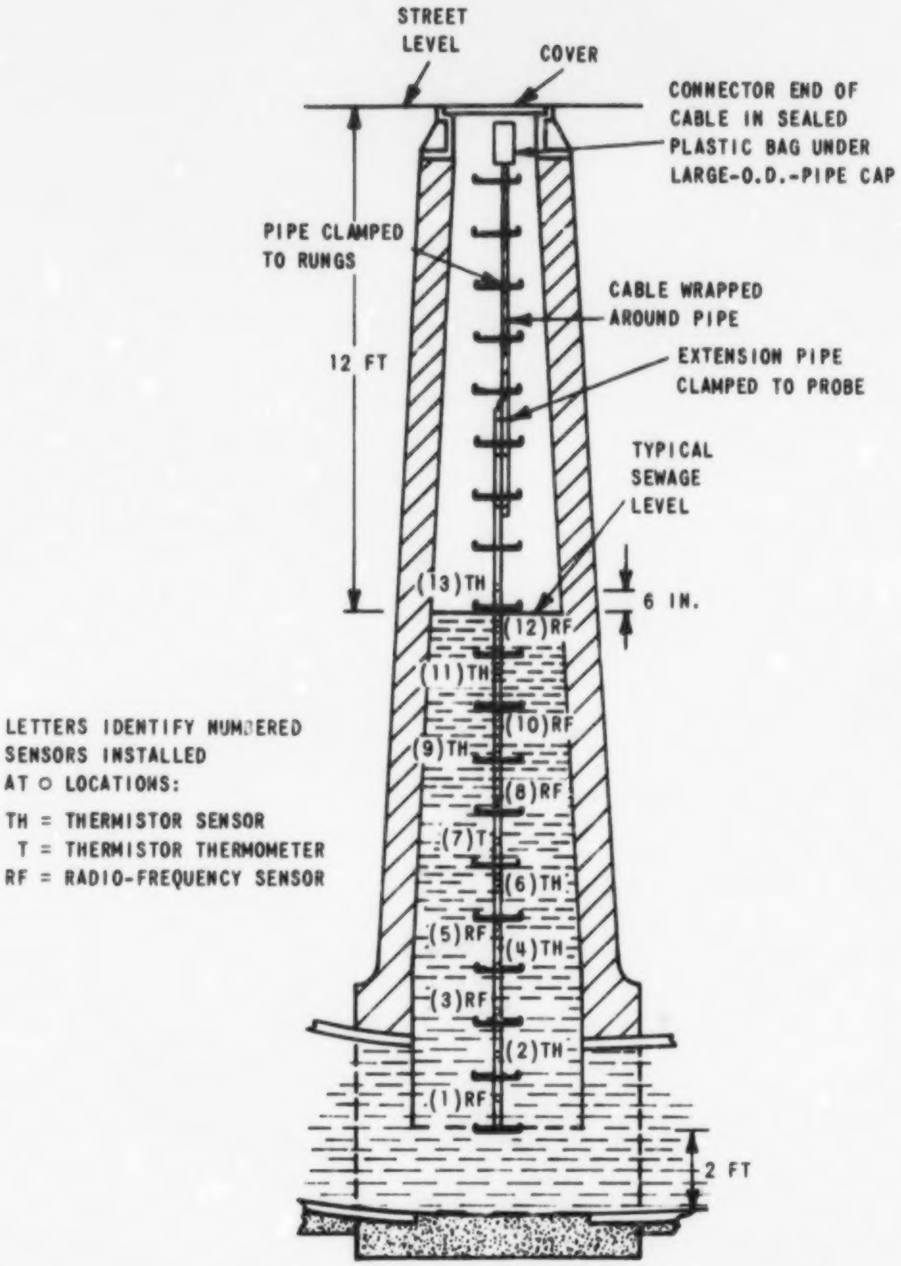
STREET LEVEL
COVER
CONNECTOR END OF CABLE IN SEALED PLASTIC BAG UNDER LARGE-O.D.-PIPE CAP
PIPE CLAMPED TO RUNGS
CABLE WRAPPED AROUND PIPE
12 FT
EXTENSION PIPE CLAMPED TO PROBE
TYPICAL SEWAGE LEVEL
(13)TH
6 IN.
(12)RF
(11)TH
(10)RF
(9)TH
(8)RF
(7)T
(6)TH
(5)RF
(4)TH
(3)RF
(2)TH
(1)RF
2 FT
LETTERS IDENTIFY NUMBERED SENSORS INSTALLED AT ○ LOCATIONS:
TH = THERMISTOR SENSOR
T = THERMISTOR THERMOMETER
RF = RADIO-FREQUENCY SENSOR

Figure 42 CROSS SECTION OF MANHOLE 3 OF MEMORIAL DRIVE INVERTED SIPHON SHOWING INSTALLATION OF INSTRUMENTATION PROBE

Figure 43 POLYVINYL CHLORIDE SPAR BUOY SENSOR

Experience with the RF conductivity probe showed that it was capable of withstanding the sewer environment for many months without maintenance. Data from the unit were transmitted on an hourly basis and a continuous record of oil depth in the inverted siphon could be achieved at the remote location.

THIN FILM OIL DETECTORS

For detection of thin films of oil ranging from less than 1 wavelength in thickness to several millimeters, an optical sensor was developed. Most oils are effectively opaque in the near-ultraviolet (UV) region of the spectrum. Pure, freshly distilled mineral oil of pharmaceutical quality is transparent at this wavelength, but quickly becomes opaque upon exposure at an air-water interface. In addition, commercial grades of oil are colored by impurities and are opaque in the wavelength region from 300 to 400 nanometers. In the 600 nm region of the spectrum, however, thin films of most of these oils are fairly transparent. Oil films in the thickness range from 1 micron to 1 millimeter can, therefore, be detected even in the presence of partially opaque debris, for example, silt, by a differential transmissometer which compares transmission at 360 nm (near UV) with that at 600 nm (orange-red).

An oil sensor, based on the above principle, was designed, fabricated, and tested in the Buffalo sewer system. The general form of the thin film sensor is shown in Figure 44. A neon discharge bulb and an argon discharge bulb are flashed in succession. The outputs of the bulbs, which are directly exposed to sewage, are sensed by a cadmium sulfide photoresistor after passage through either a surface layer, or two centimeters of oil emulsified with sewage; that is, this unit can be used for detecting surface layers or oil in emulsified form in bulk water. The output of the photocell is used to vary the frequency of the crystal oscillator of a citizen's band transmitter. The thin film oil sensor with its battery powered supply, timers, and transmitters, was installed in a 55-gallon drum, largely filled with concrete to discourage vandalism. For purposes of this evaluation, the device was set near an off-road manhole which connected to an oil-polluted sewer. This installation is shown in Figure 45. Oil in this sewer is believed to come from a nearby railroad yard. Leaching of calcium carbonates from limestone constituting the road bed of this yard resulted in the coating of the optical components by scale which has to be removed at intervals of one to several weeks. Leaves and pieces of cloth were occasionally wrapped around the apparatus, but these can probably be excluded by a simple screen.

The thin film oil detector was calibrated in a chlorothene (1, 1, 1 trichloroethane) solution of oil. Initially, the probe was submerged in a known quantity of fresh, presumably oil-free solvent. A slight relative attenuation of the ultraviolet transmission was noted at this time. Oil was then added, first a drop at a time and then in quantities

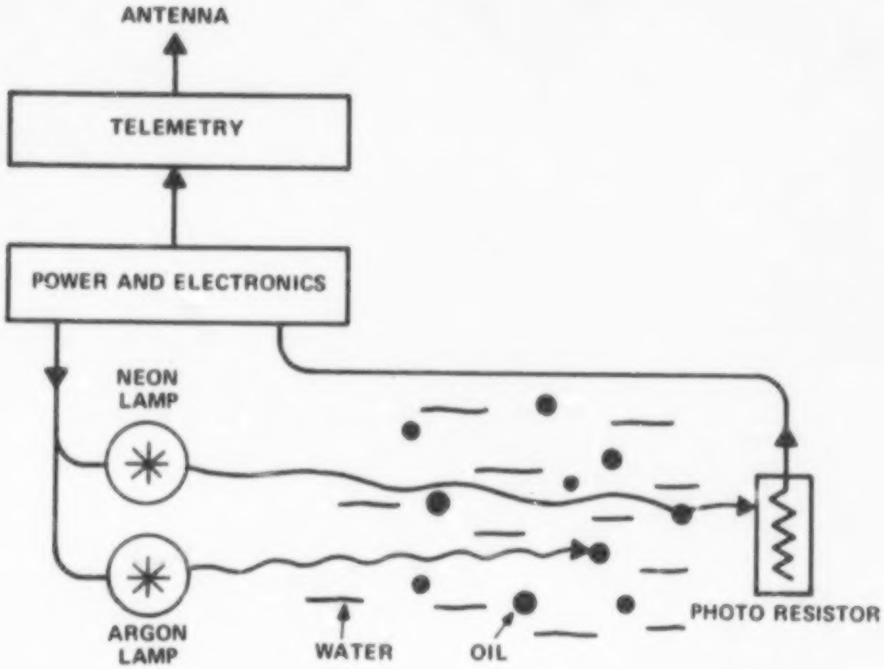

Figure 44 NEAR-ULTRAVIOLET OIL SENSOR

of several cubic centimeters, and the ratio of pulse height at the photosensor during the UV pulse to that observed during the orange pulse was measured. Since this ratio should remain unchanged in clean water, the readings were normalized to the ratio in fresh chloroethane.

Other methods must be used to detect oil films thinner than a wavelength of light. Under the Buffalo River Program, consideration was given to a device for detecting thin films of oil based on capillary wave propagation. The effect of very thin oil films on the damping and propagation of capillary waves is generally well known. A laboratory demonstration unit based on this principle was constructed. The capillary waves were produced by a loud speaker operating at low audio frequencies in the range of 40 to 120 Hz. The wave detector consisted of a small pick-up paddle attached to a phonograph cartridge. The apparatus is shown in Figure 46. The phase and amplitude of the received waves are compared with the loud speaker excitation. The presence of oil affects the propagation velocity of the induced waves. On the basis of experience gained with the laboratory demonstration model, it was concluded that a device based on this principle should be capable of operation in open water if certain changes are made. A further description of this concept is given in Reference 3.

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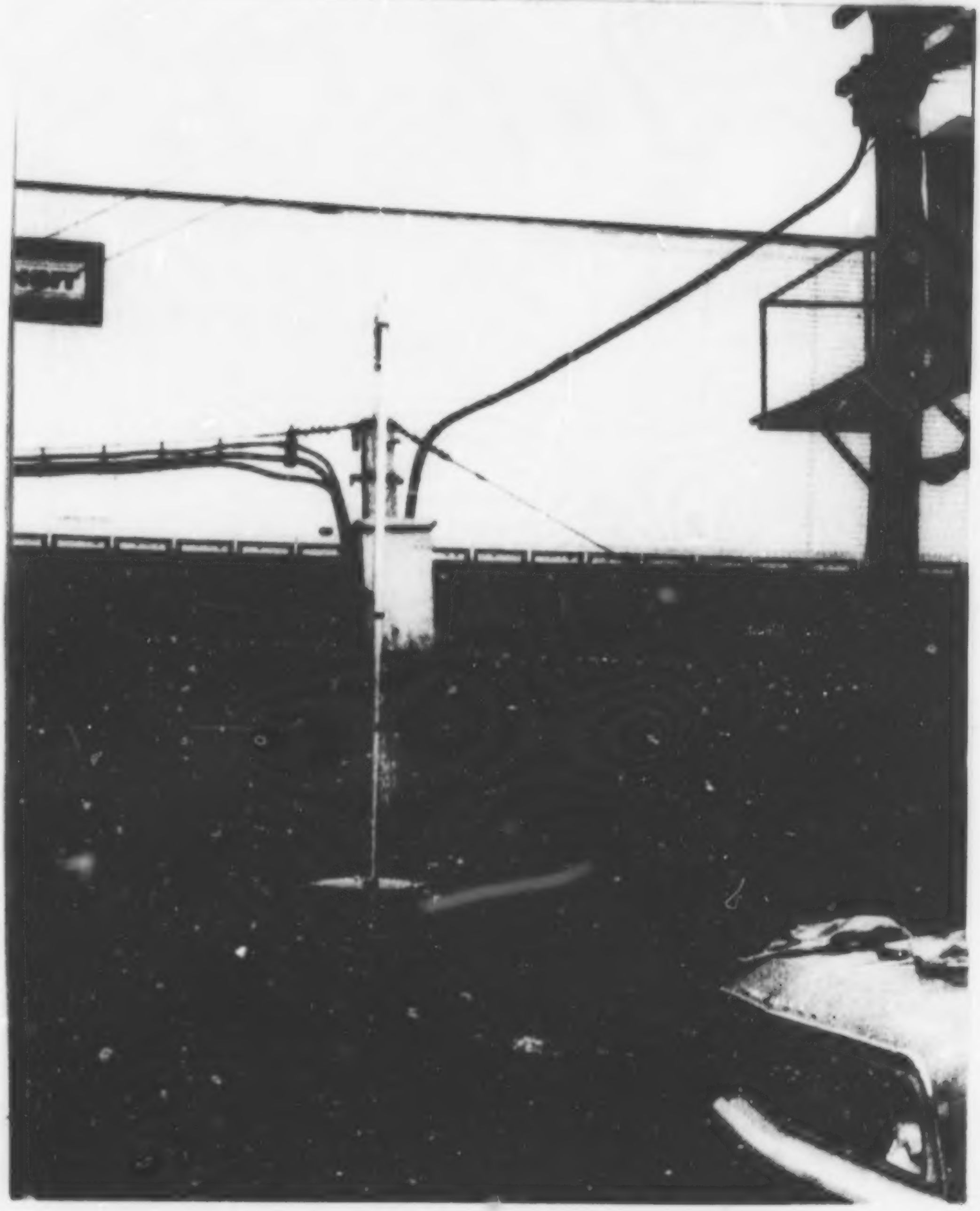

Figure 45 UV SENSOR INSTALLATION

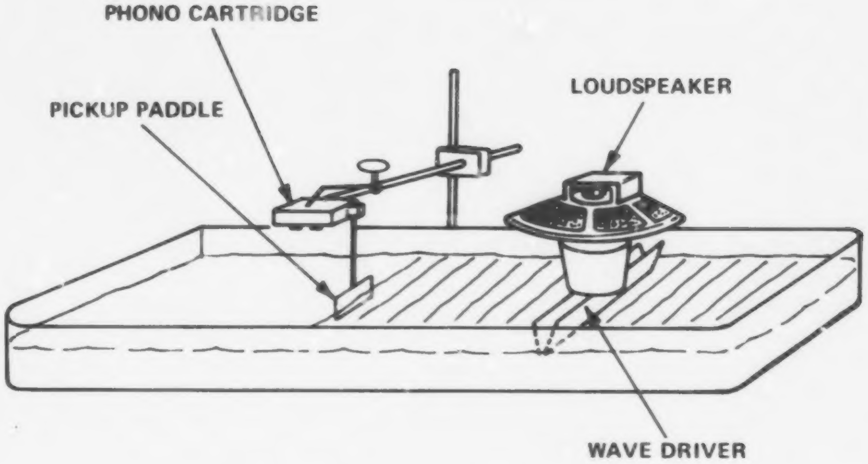
PHONO CARTRIDGE
PICKUP PADDLE
LOUDSPEAKER
WAVE DRIVER

Figure 46 CAPILLARY WAVE PROPAGATION APPARATUS

SECTION XI

INVERTED SIPHONS FOR OIL TRAPPING

The deliberate or accidental discharge of oil into sewer systems presents two potential problems. First, excessive quantities of oil can interfer with the sewage treatment process. Even if the quantities are not sufficient to cause interference, they will be discharged along with the treated sewage into the receiving waters unless adequate oil removal and storage facilities are available. Second, in many municipalities, storm sewers and sanitary sewers are combined. During heavy rains, the combined flow in the sewers exceeds the capacity of the sewage treatment plant, and the excess flow containing both storm water and sewage is discharged into waterways. In the case of Buffalo, part of the combined flow is discharged in the Buffalo River. Thus, oil discharged into the sanitary sewer system is carried into the Buffalo River during storms as noted in the previous section on sewer instrumentation.

Clearly, the most desirable solution to these potential problems is to prevent oil from being discharged into the sewers in the first place. Although regulations are in effect which prohibit the discharge of oil into sewers, strict enforcement of these regulations is difficult and costly. Clandestine discharges, often detected after the fact, are often difficult to associate with the source. A detection system consisting of a network of oil detectors located at selected points in the sewers, could become an important asset to an enforcement program, as noted in the previous section. While strict enforcement programs can greatly reduce the possibility of oil discharges into sewers, accidental or clandestine discharges will occur from time to time. Therefore, it is desirable to have a means for trapping oil in sewers in order to prevent its flow into the treatment plant or into watercourses during periods of storm. Methods for trapping oils in sewers is the topic of this section.

Prior to initiation of the Buffalo River Program, it was known from experience that oil accumulation occurred in the manhole chambers of inverted siphons. Inverted siphons are used in sewer lines when one sewer crosses another sewer, a water main, or a gasline at the same elevation. The sewer line is dropped below its normal level for a distance sufficient to clear the interfering line. Figure 47 is a diagram of an inverted siphon installation located in the Buffalo sewer system at Memorial Drive and Gibson Street. In this case, the inverted siphon was necessary to cross a storm sewer located at the same depth. Periodically it is necessary to pump out the large quantities of oil which accumulate in manholes No. 2 and No. 3. Oil accumulations corresponding to oil depths greater than 10 feet have been observed in manhole No. 2. This corresponds to more than 900 gallons of oil.

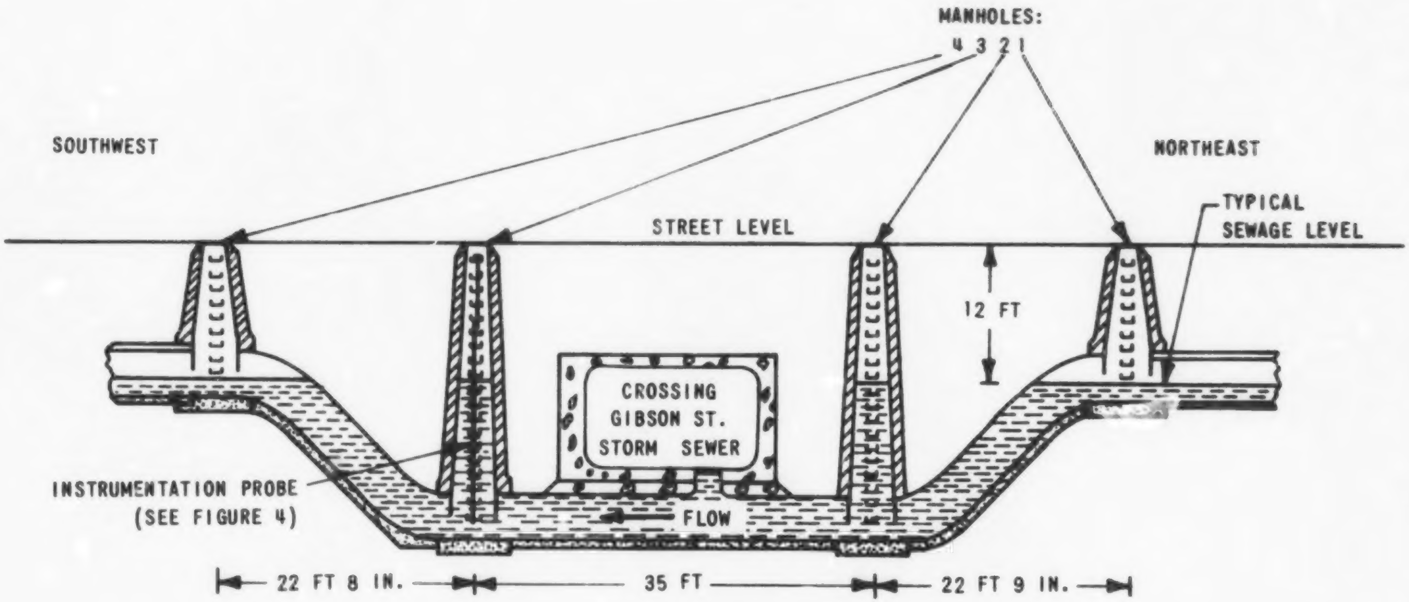
MANHOLES:
4 3 2 1
SOUTHWEST
NORTHEAST
TYPICAL SEWAGE LEVEL
STREET LEVEL
12 FT
CROSSING GIBSON ST. STORM SEWER
INSTRUMENTATION PROBE (SEE FIGURE 4)
FLOW
22 FT 8 IN.
35 FT
22 FT 9 IN.

Figure 47 CROSS SECTION OF MEMORIAL DRIVE INVERTED SIPHON

The present program involved an extensive study of the oil trapping efficiency of the particular inverted siphon configuration shown in Figure 47. This effort included monitoring of the oil accumulation in manholes No. 2 and No. 3 using oil detection sensors described in the previous sections, the collection and analysis of samples both upstream and downstream of the inverted siphon as well as in the inner manholes, and laboratory tests involving 1/12-and 1/24-scale models of the siphon.

MONITORING OF OIL ACCUMULATION IN THE SIPHON

The thick film oil detectors described in the previous section and installed for evaluation in the inverted siphon on Memorial Drive provided a large quantity of data on the oil trapping characteristics of inverted siphons. The acquired data indicate that within a period of a few days hundreds of gallons of oil can accumulate in the inner manholes of the siphon. Unusually large quantities of oil were accumulated in the siphon during March of 1969. The total amounts of oil trapped in manholes No. 2 and No. 3 in March, 1969 are shown in Figures 48 and 49, respectively. These measurements were made using the portable oil probe. The upper curves indicate the total amount of oil trapped (projected quantity) including the oil pumped from the siphon. The lower curves indicate the actual oil depth at the time the measurements were made. Figure 48 indicates that from the period of March 6 to March 21 over 1300 gallons of oil were trapped by manhole No. 2. Figure 48 indicates that during the same period manhole No. 3 trapped more than 750 gallons of oil. Thus, in a 15-day period more than 2,000 gallons of oil were trapped in this inverted siphon. The large quantities of oil trapped during this period are attributed primarily to the spillage of diesel fuel oil at a nearby railroad terminal during refueling operations. The monitoring activity at this particular inverted siphon and the associated large quantities of oil that were detected received considerable publicity in one of the local newspapers. As a result of a state directive, the railroad installed concrete refueling pads and a collection basin to prevent spilled oil from entering the Buffalo sewer system.

The above example illustrates the profound importance of a regular monitoring program for enforcing pollution laws.

SAMPLE COLLECTION AND ANALYSIS

The monitoring studies described above, based on oil depth measurements only in the inner section of the inverted siphon, provided useful information on the general trapping characteristics of this type of configuration. However, the evaluation of the overall effectiveness of an inverted siphon for trapping oil requires information on the amount of oil entering and exiting the siphon as well as on the amount of oil actually collected in the inner manhole. The evaluation should also include identification of the types of oily material normally flowing in the sewers at siphon locations. A carefully planned sampling program

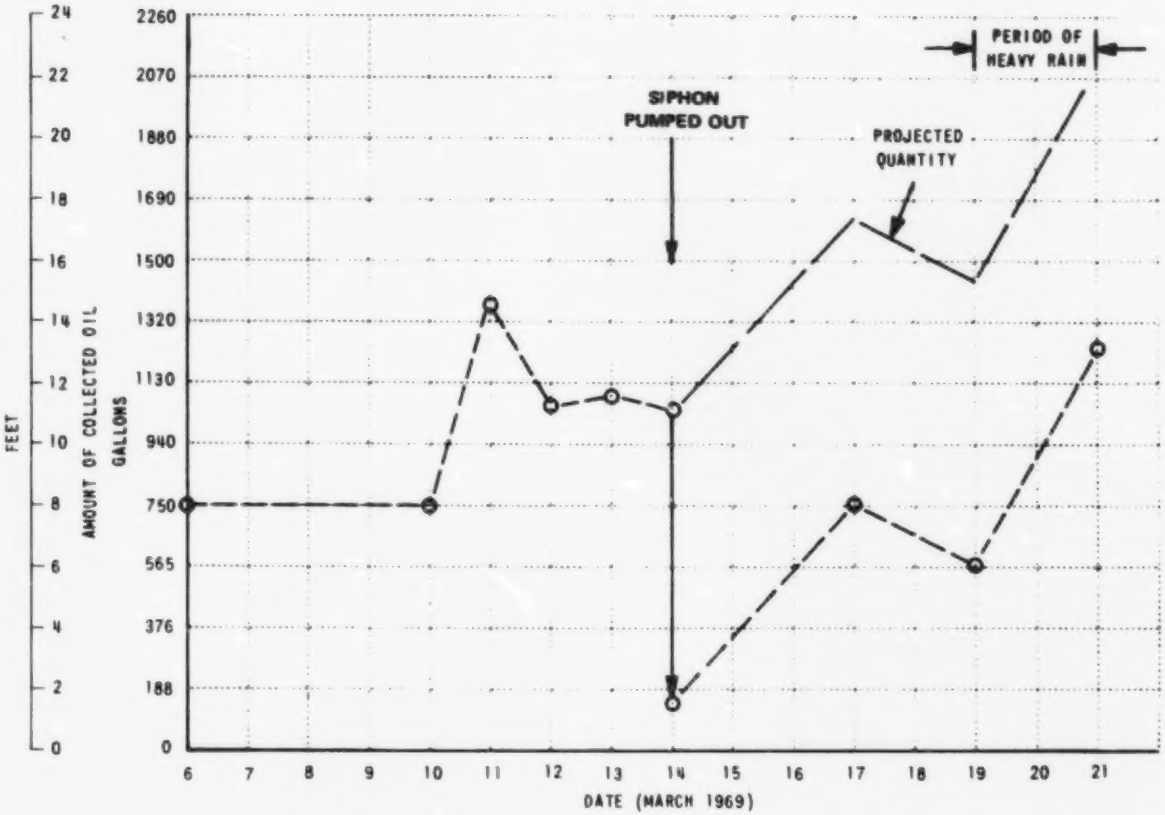

Figure 48 OIL ACCUMULATION MEASURED USING PORTABLE PROBES IN MANHOLE 2 OF MEMORIAL DRIVE INVERTED SIPHON

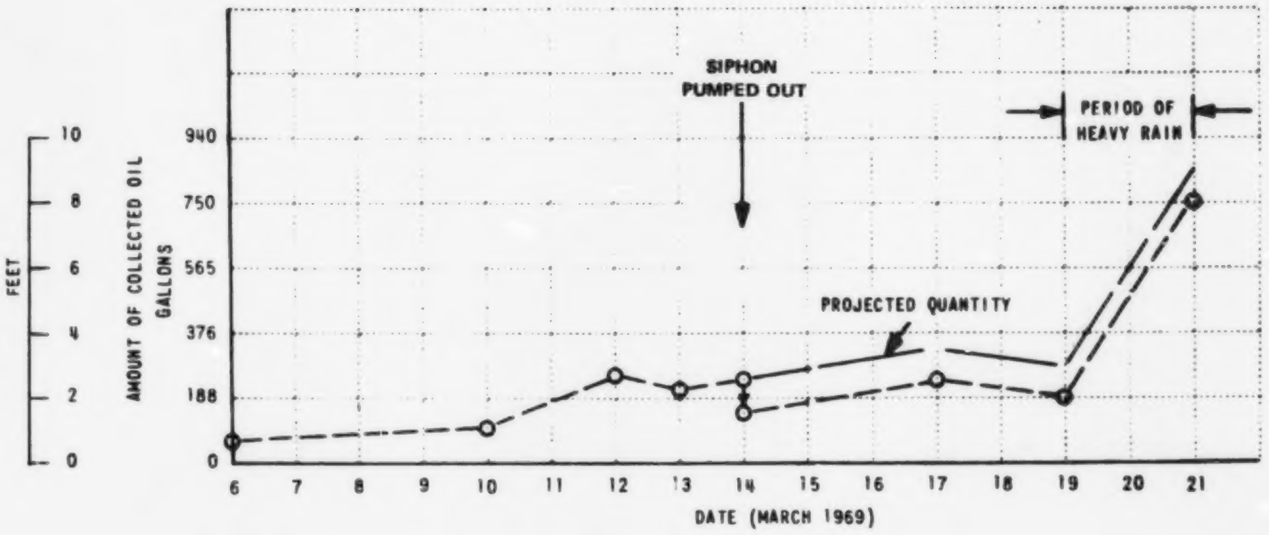

Figure 49 OIL ACCUMULATION MEASURED USING PORTABLE PROBES IN MANHOLE 3 OF MEMORIAL DRIVE INVERTED SIPHON

was initiated in order to obtain the required information. The sampling program was accompanied by an intensive study of the characteristics of the samples obtained.

During 1969, one extensive sampling period extended over a full week, night and day. Continuous results were obtained over the final 5 days of this 7-day period, wherein the influent and effluent streams were sampled every 30 minutes at manholes No. 1 and No. 4 (see Figure 47), respectively. These samples were composited daily and analyzed for the total concentration of hexane-extractable materials and for the relative proportions of oils of biological and of petroleum origins. In addition, the central manholes, No. 2 and No. 3, were sampled every day and at the beginning and end of the program. The samples from the two inner manholes were taken at 2-foot depth intervals starting at the top of the oil column and analyzed for total hexane extractable materials only. The purpose of the latter sampling was to attempt to relate the inflow content and the outflow content to the change of net storage in the inverted siphon.

Prior to initiation of the sampling program, the oil and solid burden accumulated in the siphon manholes were completely removed. The flow volume through the inverted siphon section was calculated by means of the Manning equation, which relates flow volume to the hydraulic properties of the channel. The required data on flow depth in the inlet and outlet sections were recorded by a staff gauge.

The overall results obtained for this week of sampling indicated a negative trapping efficiency for oil and the bulk water. However, samples collected from manholes No. 2 and No. 3 during the test period indicated the significant increase in storage. Dry weather flow conditions occurred during the sampling period with the exception of one short period when a high intensity storm recorded approximately 0.75 inch of rainfall at the Buffalo airport station. The effects of the storm were noted in the gauging data for approximately 2 hours with peak flows reaching 20 MGD compared with an average of 1.65 MGD for the entire sampling period and a dry weather flow average of 1.43 MGD. Omission of the data included in the period of heavy rainfall and reevaluation of the inflow-outflow data for this particular sampling effort indicated that, at best, the inverted siphon trapped 20 percent of the potential emulsified oily pollutants entering in the bulk water. However, on the basis of other tests performed throughout the program, it is concluded that in general, the inverted siphon sewer configuration has low (nearly zero) efficiency for trapping emulsified oil carried in the bulk waters of the sewer.

Infrared analyses of the extractable matter carried in the bulk water entering and exiting the inverted siphon section of the sanitary sewer showed that the influent and effluent are essentially identical and that the transit of the bulk water through the inverted siphon does not modify either its properties or its content in any significant way.

During the 1969 sampling season, an investigation was also made of the effects of the inverted siphon on pollutants carried on the surface of the water. Surface samples upstream and downstream of the inverted siphon section and in the inner manholes were collected using a prism dip technique. (See section on oil sampling, identification and analysis). The collected surface sample was then analyzed by a spectroscopic technique based on multiple internal reflection of light within the prism. Comparisons of the spectra for samples collected at manholes No. 1 through 4 indicated that (1) the spectrum for manhole No. 1 represented primarily products of biological origin with the predominance of fatty materials (example, triglycerides) and proteins (A simple mixture of cooking greases and proteins would match this spectrum almost exactly) (2) the spectrum for the sample collected at manhold No. 2 typified the surface of a very deep column of accumulated oils and greases in this manhole, which most often included some very large vegetable fragments as well, (3) the spectrum of the sample collected for manhole No. 3 showed that most of the proteinaceous material is well trapped in the second manhole and does not enter the third manhole standpipe. Otherwise, the oil fractions in manhole columns 2 and 3 are essentially identical, and (4) the spectrum for oil exiting the inverted siphon collected at manhole No. 4 showed minor traces of oil pollutants.

On the basis of this comparison and those made for other sampling tests, it is concluded that the inverted siphon is nearly 100 percent effective for trapping surface-borne oils of all types.

Analyses of samples collected during the investigation of the inverted siphon at Memorial Drive provided insight into the character of the oil pollutants which accumulate in the inner manholes of this siphon. Both gas chromatography and infrared spectroscopy were used in these analyses. A summary of these findings is presented in Figure 50.

MODEL STUDIES

To determine which scaling laws are valid for predicting the flow behavior of oil-water systems, an investigation was undertaken of the scale models of the inverted siphon at Memorial Drive and Gibson Street, since much data had been acquired on the behavior of this particular siphon. Two scale models were constructed: one at 1/12 scale and the other at 1/24 scale. Since the diameter of the main pipe in the Memorial Drive inverted siphon is 48 inches, the corresponding model dimensions were 4 inches and 2 inches. Photographs of the models taken as construction was nearing completion are presented in Figure 51. A complete description of the models is given in Reference 4. While a single model would be sufficient to test scaling relationships by comparison with the behavior of the full-scale system on Memorial Drive, two laboratory models provided a more practical approach and allowed greater flexibility in selecting oil and water flow rates. The detailed measurements required to establish scaling relationships would have been

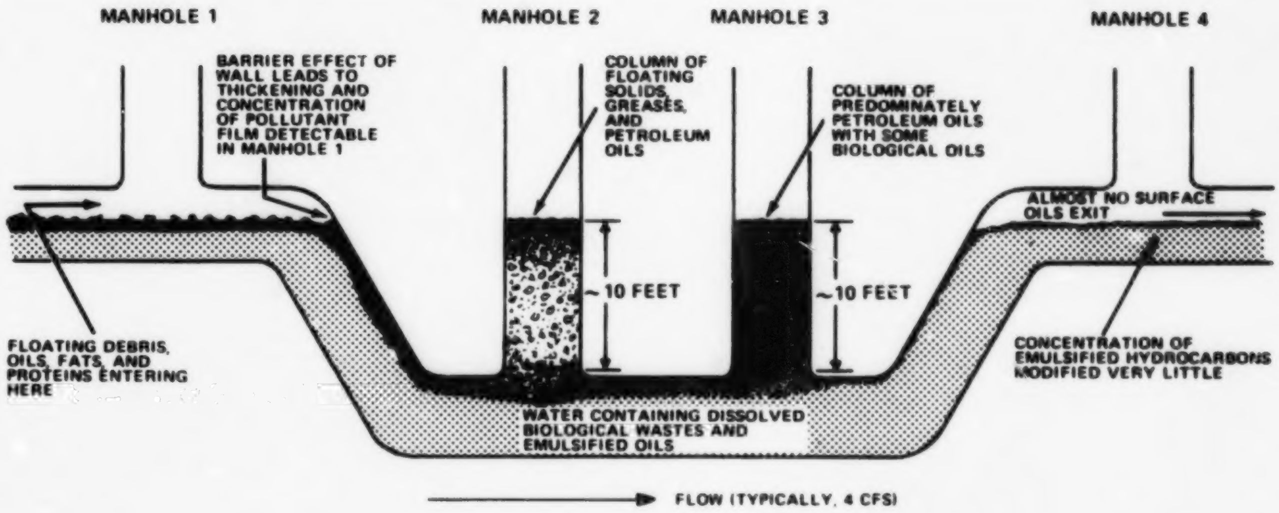
MANHOLE 1
MANHOLE 2
MANHOLE 3
MANHOLE 4
BARRIER EFFECT OF WALL LEADS TO THICKENING AND CONCENTRATION OF POLLUTANT FILM DETECTABLE IN MANHOLE 1
COLUMN OF FLOATING SOLIDS, GREASES, AND PETROLEUM OILS
COLUMN OF PREDOMINATELY PETROLEUM OILS WITH SOME BIOLOGICAL OILS
ALMOST NO SURFACE OILS EXIT
~10 FEET
~10 FEET
FLOATING DEBRIS, OILS, FATS, AND PROTEINS ENTERING HERE
CONCENTRATION OF EMULSIFIED HYDROCARBONS MODIFIED VERY LITTLE
WATER CONTAINING DISSOLVED BIOLOGICAL WASTES AND EMULSIFIED OILS
FLOW (TYPICALLY, 4 CFS)

Figure 50 INVERTED SIPHON SECTION OF SANITARY SEWER AND ITS FUNCTION AS AN OIL TRAP FOR SURFACE-LOCALIZED POLLUTANTS

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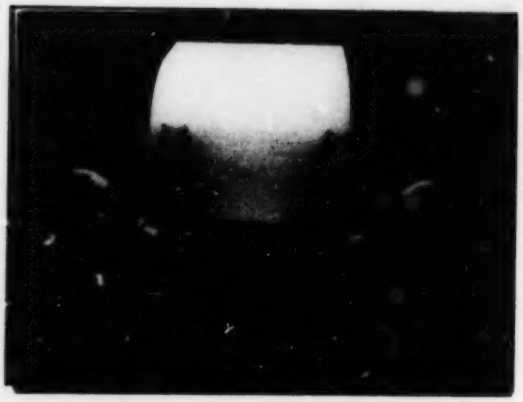
VIEW OF TWO-INCH MODEL SHOWING SUPPLY AND FLOW CONTROL TANKS



VIEW OF MANHOLE CHAMBERS FOR TWO-INCH MODEL

VIEW OF FOUR-INCH MODEL

Figure 51 PHOTOGRAPHS OF INVERTED SIPHON MODELS

virtually impossible to obtain in the full-scale siphon, and neither the oil flow nor the water flow could be controlled to desired levels or maintained constant over sufficiently long test periods.

The oil flow rates and water flow rates were scaled according to both Froude number and Reynolds number. The oil was metered into the systems well upstream of the first manhole. The oil quickly surfaced so that by the time the oil-water mixture reached manhole No. 1 the oil was completely contained on the surface. As the experiments progressed, observations concerning the behavior of the oil were noted, and in particular, the amount of oil accumulated in the inner manhole chambers No. 2 and 3 of the model siphon were recorded as a function of time. The results of the 1/24-scale model and the 1/12-scale model were compared for both Froude number scaling and Reynolds number scaling. It was concluded, not unexpectedly, that Reynolds scaling was not appropriate for the inverted siphon configuration for oil-water systems. On the other hand, the experiments based on Froude number scalings showed good agreement between the 1/24-scale model and the 1/12-scale model. While further testing would be required in order to verify that Froude modeling would be appropriate under all conditions of flow, it appeared that Froude scaling is appropriate for the ranges of values tested in this program.

The general behavior of the inverted siphon system for trapping oil is as follows. A thickening oil slick accumulates upstream of the first 45-degree downward bend. When sufficient oil accumulates at that point, some of it is then carried down the first bend into the second manhole chamber. Virtually no oil proceeds into manhole No. 3 until the chamber for manhole No. 2 is completely filled. Likewise, essentially no oil appears downstream of the inverted siphon until the third manhole chamber has been completely filled. This verifies the observation made in the actual inverted siphon; namely, that for normal flows the inverted siphon is nearly 100 percent effective for trapping surface oils. A sequence of photographs showing oil-trapping characteristics of the 2-inch inverted siphon model is given in Figure 52.

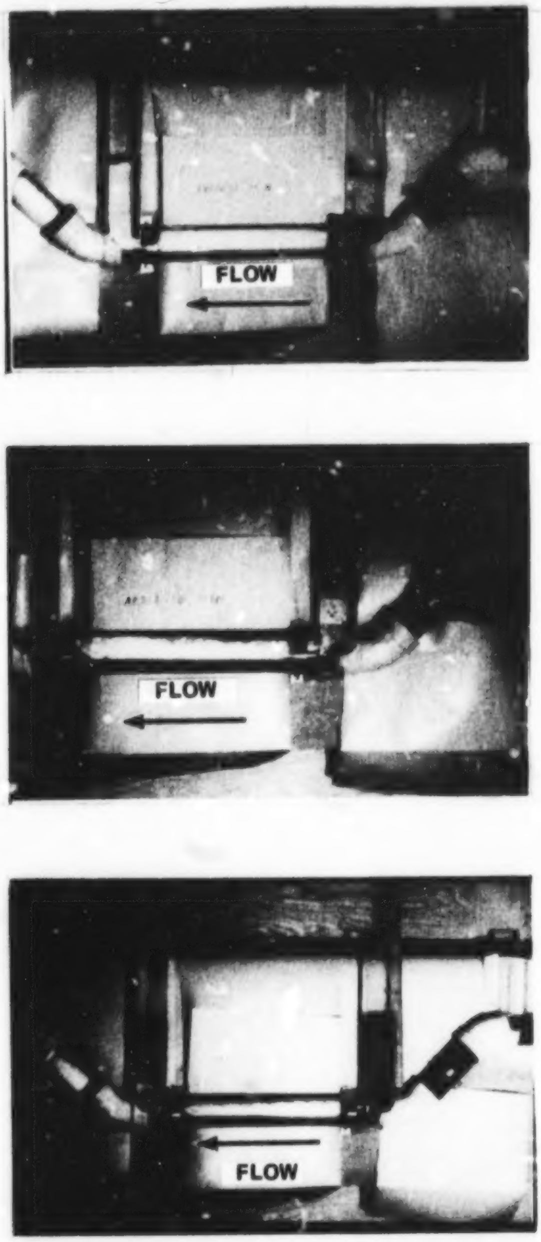

FLOW
FLOW
FLOW

Figure 52 SEQUENCE OF PHOTOGRAPHS SHOWING OIL TRAPPING CHARACTERISTICS OF TWO-INCH INVERTED SIPHON MODEL

SECTION XII
OIL AND DEBRIS REMOVAL BOAT

In the original grant application for the Buffalo River Project, it was proposed to procure a boat-mounted, portable skimming system. Observations made throughout the present program indicate that this original concept has validity in that no single location was found that would be suitable for mounting a permanent oil skimming system. The combination of wind and current effects tend to shift oil accumulations in an unpredictable manner. Furthermore, a system is required for cleaning up accidental oil spills that occur from time to time. This section describes the oil and debris recovery boat that was procured as part of this project.

The boat is named in honor of Samuel Wilkeson, a former Mayor of Buffalo in 1836, who had earned the title, "Harbor Maker of Buffalo", for spearheading the creation of the harbor and actually laboring with the workmen on its construction in 1820. The boat was constructed by the Grafton Boat Company of Grafton, Illinois. It has an overall length of 40 feet plus a 3-foot extension platform close to the water surface at the stern for oil sampling and for skimmer operation. It has a beam of 14 feet and a draft ranging from 18 inches to 27 inches depending upon the load. It is powered by two 135-BHP Perkins diesel engines. Access to the diesel engines is through double raised hatches on the deck. It has 24-inch diameter twin screws with backing rudders. A 6 feet by 8 feet cabin houses a central control station which includes Morse engine controls and hydraulic steering. The boat has a top speed of 10 mph and a fuel oil capacity of 100 gallons. Electrical power for operating equipment is derived from a diesel-powered Kohler generator mounted at the stern of the boat having a capacity of 15 KW (110/220 volts, 3 phase, 60 cycle). Four 800 gallon tanks mounted below the deck and in the forward half of the hull are available for storing retrieved oil. An overall view of the boat is shown in Figure 53.

For debris retrieval, an hydraulically operated crane is mounted on the deck at the bow of the boat. This unit is designated as a "Mariner 60 Husky/Hyhoe hydraulic log and pulp wood loader." It is manufactured by Husky Hydraulics, Inc. of Two Harbors, Minnesota. The hydraulic pressure is derived from a power take-off unit connected to the starboard diesel engine. The lifting capacity of the crane ranges from 4500 to 14,000 pounds, depending on the reach. The maximum horizontal reach is 19 feet 2 inches measured from the center of the pivot point. The maximum vertical reach is 23 feet 3 inches from the deck. The crane can be rotated a full 430 degrees in either direction. The unit includes a power operated winch and a specially designed basket for debris removal. A chair and central control console are provided for the operator at the rear of the boom. Figure 54 shows the debris removal crane in operation.

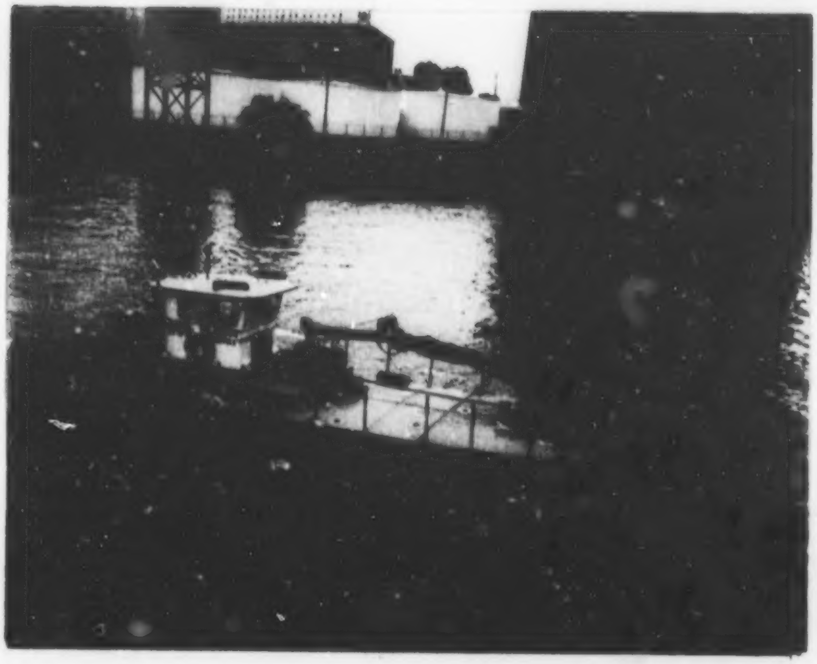


Figure 53 THE SAMUEL WILKESON (OIL AND DEBRIS RETRIEVAL BOAT)

Figure 54 DEBRIS CRANE IN OPERATION

At this writing, the oil pick-up system is in the process of being procured. It will consist of a Moyno pump followed by an oil-water separator system. The pick-up capacity will be approximately 50 gallons per minute. Detailed specifications for the oil-water separator are in preparation.

Additional storage capacity for retrieved oil and/or debris is provided by a specially designed Dempster Dinosaur trash container unit, which serves as a floating barge (see Figure 55). One end door of this unit is hinged at the top and has a water-tight, rubber seal around its edge. The door is secured by a system of screw-lock clamps. The weight of the entire unit is 5400 lb unloaded. The oil/debris storage compartment is 20 feet long, 8 feet wide, and 6 feet high. This unit will be floated next to and towed by the oil pick-up boat during recovery operations. When the oil/debris compartment is filled to capacity, the unit can be floated to shore and retrieved at a ramp by a pick-up truck specially designed to transport the Dempster Dinosaur units with a bottom skid for this purpose (see Figure 56). This concept eliminates the need for additional handling of debris or oil that would be required to transport it from a storage vessel to a truck on land.

In use, the oil/debris recovery boat will most often be used with portable booms. For transporting oil containment booms to the site of the spill, a 24-foot-long trailer was specially constructed. The trailer has storage capacity for twenty-four 25-ft boom sections. The trailer loaded with booms is shown in Figure 56.

SAMUEL WILKESON
ENGINEERING
CITY OF BUFFALO

Figure 55 OIL AND DEBRIS STORAGE BARGE

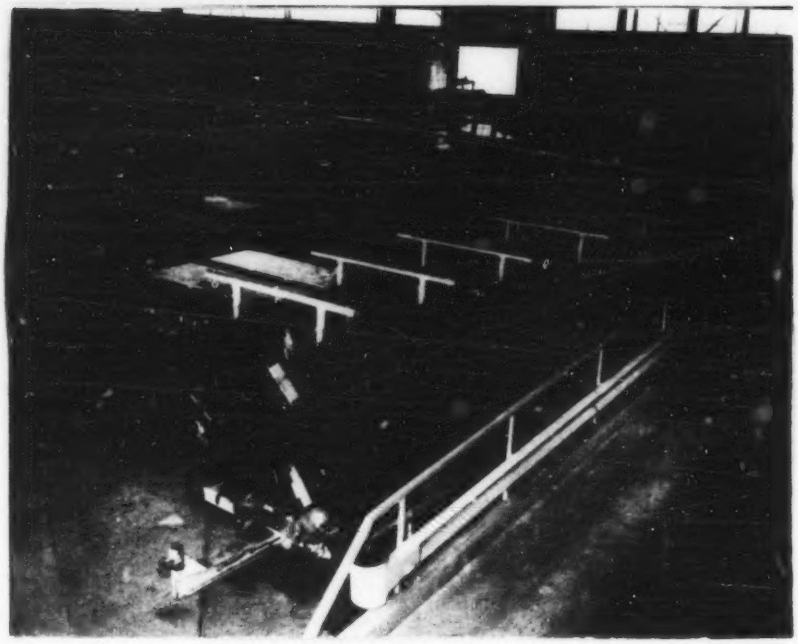


Figure 56 BOOM TRAILER

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SECTION XIII
ACKNOWLEDGMENTS

This project was carried out by Cornell Aeronautical Laboratory, Inc. with financial support of the Environmental protection Agency and with technical assistance from Mr. Harold Bernard, Chief, Agricultural and Marine Pollution Control Branch, and Mr. Richard R. Keppler, Project Officer for the EPA. The staff of the Water Quality Group of the EPA Hudson-Delaware Basin Office, at Edison, New Jersey--especially, Mr. Leo McCarthy and Dr. Joseph Lafornara--provided technical advice and data on numerous occasions throughout the term of the project and arranged for collection of samples from an oil spill incident on the Schuykill River, Pennsylvania, which were analyzed at EPA request along with samples from candidate sources of the oil. The cooperation of Mr. Herbert Anderson, formerly of the Rochester, New York, office of the EPA, is acknowledged in initiating the project and in solving problems which arose at that time.

The support of the Mayor of the City of Buffalo, New York, the Honorable Frank A. Sedita, is acknowledged with thanks. The assistance of Mr. John F. Downing, Commissioner of Public Works; and Mr. Raymond Slojkowski, City Engineer, is also appreciated. Special thanks are due Mr. Thomas J. Lyons, Associate City Engineer, who served as Program Manager for the City and who provided valuable assistance throughout the course of the program.

In addition to providing financial support for the program, the Buffalo Sewer Authority was extremely cooperative in making personnel available for assistance throughout the program in providing survey data for the Buffalo River and its cooling water project. Sincere thanks are extended to Mr. Gillman J. Laehy, General Manager of the Buffalo Sewer Authority, and members of his staff--particularly, Mr. John Kutch, Jr., Principal Engineer; Mr. Earl Broxup, Senior Engineer; Mr. Richard A. Kressin, Associate Chemist; Mr. Louis Gugliuzza, Chemist; and Mr. Salvatore Pecoraro.

Thanks are also due Mr. Eugene F. Seebald, formerly Buffalo Regional Director of Public Health Engineering, New York State Department of Health, for concern with the problem and assistance in developing the concepts which led to formulation of the project; the Buffalo Regional Office of the New York State Department of Health--particularly, Mr. Louis M. Violanti, Assistant Sanitary Engineer, for providing assistance in sampling and for the loan of equipment, and Mr. John S. Tygert, Senior Sanitary Engineer, New York State Environmental Conservation Department, for providing 1964 survey project data on the Buffalo River which were reduced by Cleveland, Ohio, Great Lakes River Basins project office of the Public Health Service and forwarded to Buffalo by Mr. Charles W. Northington, Director of the Lake Erie Program Office.

Also, appreciated is the assistance of Messrs. Thomas Reardon and Richard O'Neil of the Buffalo Harbormaster staff and of the crew of the Buffalo Fire Department's fireboat in collecting Buffalo River Samples and in providing general assistance in other efforts performed on the River; the courtesy and cooperation of Messrs. Charles Hood and Russell C. Wagner of the U.S. Geological Survey in permitting access to gauging stations on Buffalo River tributaries and in providing data on performance of the Buffalo River cooling water "improvement project;" the technical consultation provided by members of the Interface Chemistry Section of the Naval Research Laboratory in Washington, D.C., particularly Mr. W.D. Garrett and Mr. W. Barger; and the help of Dr. Robert A. Sweeney, Director, and Mr. Barry Welch of the Great Lakes Laboratory, State University College of Buffalo, in collecting samples, in providing historical data, and in identifying algal specimens.

Three organizations originated techniques or devices which are the bases for some of the approaches used in the work described. The Naval Research Laboratory, Washington, D.C., initiated the use of chemical displacing agents as piston films for controlling the size and motion of oil slicks on water. This technique was used by CAL to concentrate surface oils for collection by skimmers. To ensure that the surface oil so collected would not be replaced by additional oil contained in the water just below its surface, the amount of the latter oil was assessed using a screen sampling technique, also first employed by the Naval Research Laboratory. The small rotating drum skimmer was based on a device first used by the Scripps Institute of Oceanography.

Numerous people at Cornell Aeronautical Laboratory, Inc. participated in various technical phases of the program. D.B. Dahm and E.H. Gerber made noteworthy technical suggestions during the course of the program. R.L. Frank (no longer at CAL) served as Project Manager and Assistant Project Manager during part of the program. Dr. R.E. Baier headed the sampling and analysis task assisted by V. DePalma, W. Eadie, T. Gallagher, E. Gasiecki, R. Leonard, W. Rily, C. Rogers, and A. Wright. J. Grace headed the air barrier studies. A. Sowyrda (formerly of CAL) was involved in the initial laboratory tests, and the design and fabrication of the barrier. D. Bock headed the development of in-sewer instrumentation assisted by E. Eckert, R. Dunklin, C. Dziuba, H. Bergeman, R. Haungs, L. Meiler, and E. Torry. P. Rosenthal headed the skimmer evaluation task assisted by A. Wright. R. Haas, B. McMichael, and G. Strobel (no longer at CAL) participated in the evaluation of the trapping efficiency of inverted siphons. S. King and R. Foulis designed the debris boom.

SECTION XIV
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